14 AGRIHAN

14.1 Introduction

The island of Agrihan is located at 18°46′ N, 145°40′ E in the northern part of the Mariana Arc, 65 km north of Pagan and 100 km south of Asuncion. Also known as Agrigan and Grigan, this island is ~ 10 km wide and 7 km long, has a land area of 44.05 km^2, and is one of the largest islands of the Commonwealth of the Northern Mariana Islands (CNMI). The part of Agrihan that is visible above the ocean is the exposed part of a large volcano that rises 4000 m from the surrounding seafloor and is the second-largest volcano of the Mariana Archipelago (Fig 14.1a). Agrihan's summit, at an elevation of 965 m, is the highest point in the CNMI and is surrounded by steep slopes. These slopes are cut by narrow ridges and ravines with occasional volcanic dikes, and many coastal areas are bordered by steep cliffs (Fig 14.1b).

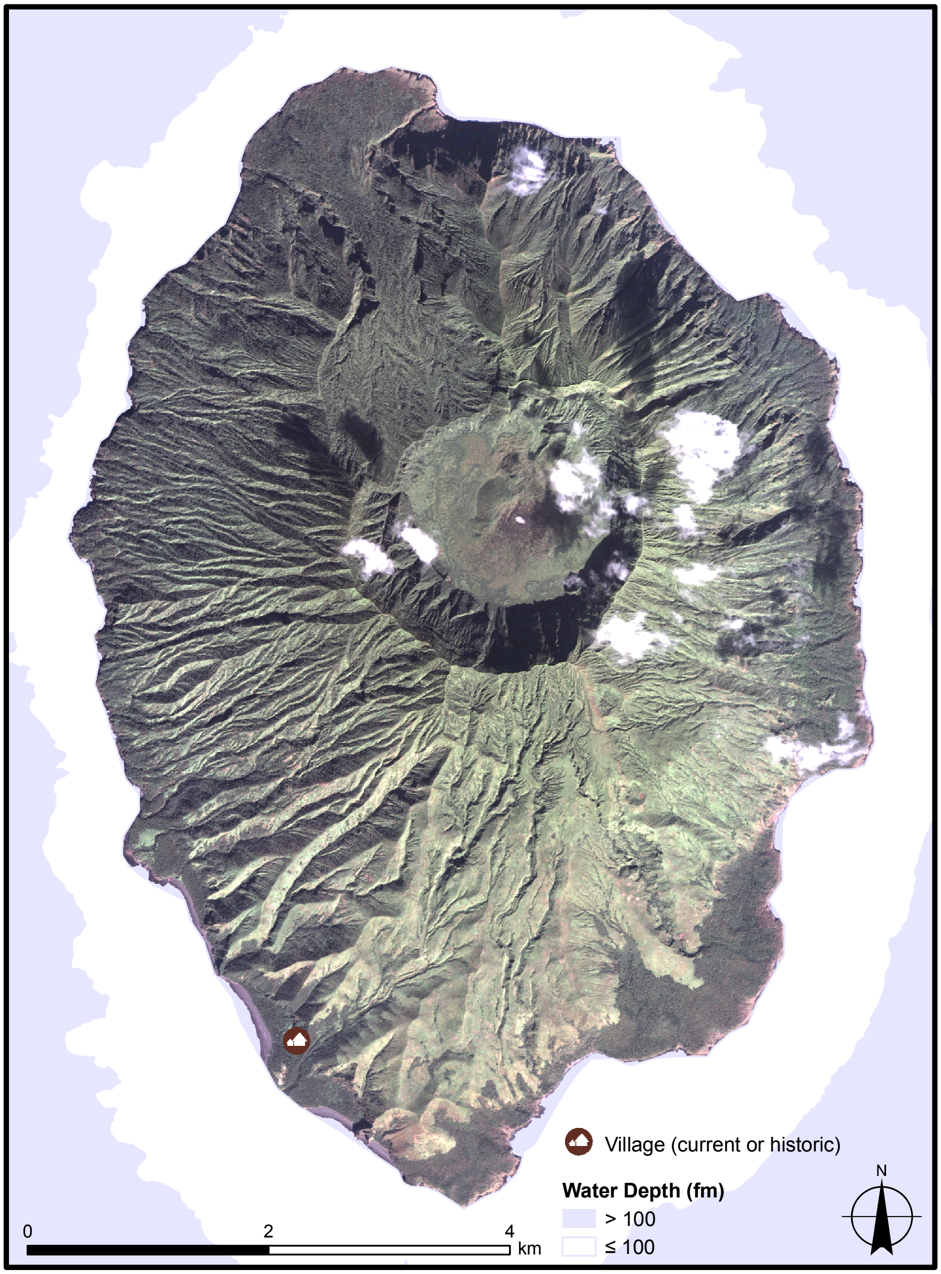


Figure 14.1a. Satellite image of Agrihan, labeled with the village where the only permanent human population north of Saipan in the Mariana Archipelago may reside (© 2005 DigitalGlobe Inc. All rights reserved).

Figure 14.1b. Agrihan as seen from the NOAA Ship *Hi'ialakai* in 2009. *NOAA photo*

14.1.1 History and Demographics

Historically, Agrihan was inhabited by the Chamorro people and notably the site of the last stand of the Chamorro against Spain. In 1810, colonists from Hawai`i and the United States attempted to establish plantations on Agrihan but were expelled from this island by Spain (Encyclopædia Britannica 2009). In 1909, while under administration by Germany, Agrihan (along with Farallon de Pajaros, Maug, Asuncion, Guguan, Sarigan, and Farallon de Medinilla) was leased to the Pagan Gesellschaft, a trading association, for exploitation of bird plumage for a period of 3 years (Spennemann 1999b). During this time, Japanese bird catchers employed on these islands may have been temporarily resident on Agrihan.

Inhabitation has been sporadic during the 20th and 21st centuries, including a U.S. military camp at one time. Volcanic activity, in both 1917 and 1990, prompted evacuation of this island's inhabitants as a precaution against more significant eruptions (Siebert and Simkin 2002–). Subsequently, on southwestern Agrihan, 1 of the 4 original villages has been re-inhabited; Agrihan is thought to have the only permanent human population north of Saipan, although this population is small (Cruz et al. 2000). During surveys conducted by the CNMI Division of Fish and Wildlife in 2000, 6 permanent residents were observed (Cruz et al. 2000). Agrihan is part of the Northern Islands Municipality of the CNMI. For this municipality, the 2000 U.S. Census recorded an official population of 6 persons, but the 2010 U.S. Census recorded no persons (U.S. Bureau of the Census 2003, 2011a).

Resettlement of Agrihan has been encouraged by the CNMI government through the *Northern Islands Homestead Act of 2008* (CNMI Public Law 16-50), which recognizes that residents of the "islands north of Saipan" have no formal homesteads, allows them to have agricultural lots and facilities, and initiates and promotes economic development. The anticipated resettlement of this island may involve increased agriculture, although cultivation would be limited because of the steep slopes and shallow soils of this island.

14.1.2 Geography

The elongated volcanic crater (1 × 2 km) is breached to the northwest, where lava flowed, extending to the coastline and forming a lava delta. This lava flow is shown on the slope map, where it contrasts with the otherwise steep ridges and ravines that dominate Agrihan's topography (Fig. 14.1.2a). The caldera floor contains relatively recent lava flows and 2 cones that may have formed during an eruption in 1917 (Siebert and Simkin 2002–).

The only recorded eruption at Agrihan occurred in 1917 and resulted in the deposition of large blocks of material and volcanic ash on a village located on the southeastern coast. Subsequent volcanic activity has been at a low level, although fumarolic and thermal activity was recorded in 1990 and 1992 (Siebert and Simkin 2002–).

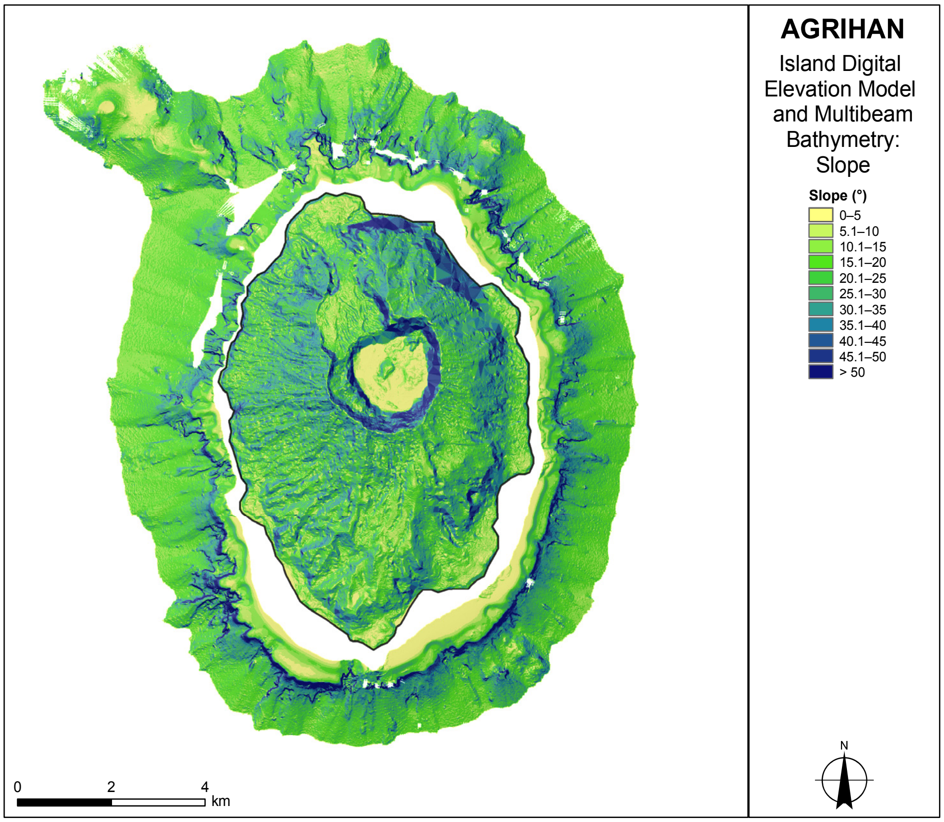


Figure 14.1.2a. Combined slope map using the digital elevation model and multibeam bathymetric data for Agrihan (grid cell size: 10 m).

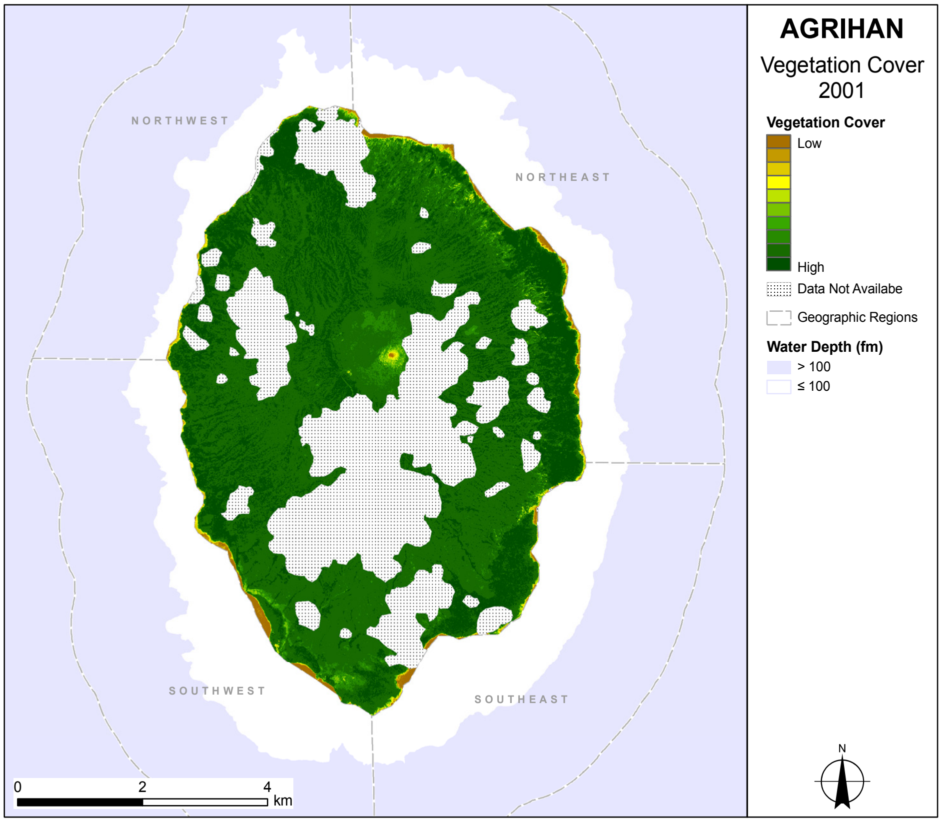


Figure 14.1.2b. Vegetation cover on Agrihan, derived using the Normalized Difference Vegetation Index from a satellite image (grid cell size: 4 m; IKONOS Carterra Geo Data, 2001). Hatched lines indicate areas where data are not available because cloud cover obscures the satellite image.

Geologically, Agrihan is dominated by volcanic deposits, composed largely of loose ash with some interbedded basaltic flows (Mueller-Dombois and Fosberg 1998). Occasional volcanic dikes also are present on the slopes (Cruz et al. 2000).

The majority of this island is vegetated (Fig. 14.1.2b) with vegetation complexes that are typical of the volcanic islands of the CNMI. Steep ash slopes are colonized predominantly by sword grass, with thickets and woods present in the narrow ravines that cut these slopes. Mixed coconut and native forest is present on the northern part of Agrihan, and coastal beaches and bluffs support mixed thickets and woods. At higher elevations, tree ferns also have been observed (Cruz et al. 2000, Mueller-Dombois and Fosberg 1998). As on many other islands that have been subject to human colonization, most of the flat areas of this island have been planted with coconuts. Other cultivated trees also are present in areas that were farmed during administration by Japan. In addition to the introduction of these non-native species, the vegetation on Agrihan has been affected by human activity, such as the clearing of large hillside areas by U.S. military personnel formerly stationed on this island (Cruz et al. 2000). Further damage to native forests has resulted from feral animals, which have caused reduction in the forest understory and erosion (Cruz et al. 2000).

Information regarding the distribution of groundwater resources around Agrihan is not available, and surface water is thought to be absent except during rainy weather (Mueller-Dombois and Fosberg 1998).

14.1.3 Environmental Issues on Agrihan

One of the main environmental concerns on Agrihan is the impact of feral animals on its native forests. Grazing by feral animals, such as pigs and goats, has resulted in the destruction of natural vegetation, including removal of the seedling understory and increased erosion (Cruz et al. 2000). Agrihan has areas of mixed and native forest, which are important in providing a habitat for native wildlife. Rats also are present, although the population size is not known, and form a serious threat to the native bird population (Cruz et al. 2000). Agrihan supports a number of forest birds native to Micronesia, including the Micronesian honeyeater (*Myzomela rubrata*) and Micronesian starling (*Aplonis opaca*). Less common are the white tern (*Gygis alba*), white-throated ground dove (*Gallicolumba xanthonura*), which is locally protected from hunting by regulation, and Micronesian megapode (*Megapodius laperouse*), which is listed federally as endangered and locally as threatened or endangered (Cruz et al. 2000; U.S. Fish and Wildlife Service; Berger et al. 2005). Micronesian megapode were found to be rare in bird surveys on Agrihan and were observed in low numbers within areas planned for homestead lots, which could be a cause for concern (Cruz et al. 2000). Agrihan also supports several groups of the Mariana fruit bat (*Pteropus mariannus mariannus*), an endemic subspecies listed federally as threatened (U.S. Fish and Wildlife Service) and locally as threatened or endangered (Berger et al. 2005), with an estimated population of 1000 bats in 2000 (Cruz et al. 2000).

As one of the few islands of the CNMI that has had and may still have a resident, if small, human population, Agrihan does not have the same isolation as do other remote islands. The encouragement of resettlement of Agrihan, along with the associated development of infrastructure that would be required, could affect the natural resources of this island if unmanaged.

14.2 Survey Effort

Biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing the coral reef ecosystems around the island of Agrihan since 2003. The spatial reach and time frame of these surveys are discussed in this section. The disparate areas around this island are often exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 4 geographic regions around Agrihan are delineated in Figure 14.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around this island. Potential reef habitat is represented by a 100-fm contour shown in white on this map.

Benthic habitat mapping data were collected around Agrihan using a combination of acoustic and optical survey methods. MARAMP benthic habitat mapping surveys conducted around Agrihan and Pagan with multibeam sonar covered a total area of 2511 km^2 in 2007. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented live coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 14.3: "Benthic Habitat Mapping and Characterization."

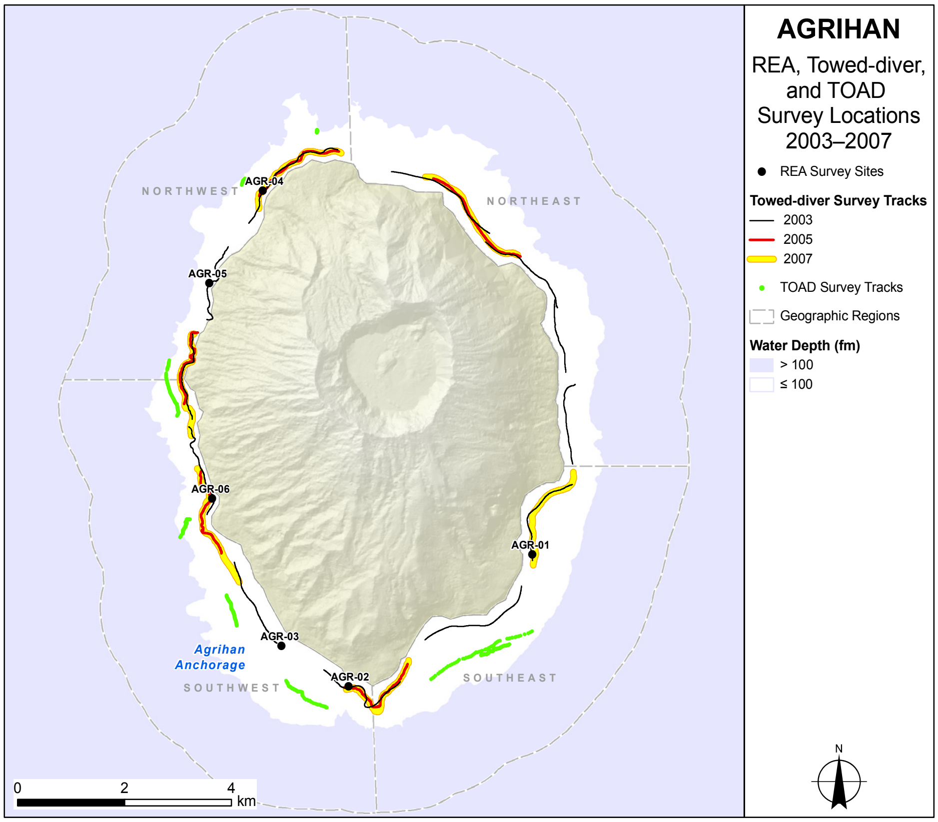


Figure 14.2a. Locations of REA, towed-diver, and TOAD benthic surveys conducted around Agrihan during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 4 geographic regions: northeast, southeast, southwest, and northwest.

Information on the condition, abundance, diversity, and distribution of biological communities around Agrihan was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 14.5–14.8: "Corals and Coral Disease," "Algae and Algal Disease," "Benthic Macroinvertebrates," and "Reef Fishes." The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 14.2a, along with their mean depths and total areas or length.

Table 14.2a. Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted around Agrihan during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		**2003**	**2005**	**2007**
Fish	Number of Surveys	6	3	3
	Mean Depth (m)	12.5 (SD 0.8)	12.8 (SD 0.3)	13 (SD 0)
Benthic	Number of Surveys	6	3	3
	Mean Depth (m)	12.5 (SD 0.8)	12.8 (SD 0.3)	13 (SD 0)
Towed Diver		**2003**	**2005**	**2007**
	Number of Surveys	12	5	6
	Total Survey Area (ha)	22.5	9.6	13.1
	Mean Depth (m)	12.6 (SD 1.7)	14.6 (SD 0.9)	14.4 (SD 1.5)
TOAD		**2003**		
	Number of Surveys	8		
	Total Length (km)	5.88		

Table 14.2b. Numbers of STRs deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Agrihan during MARAMP 2003, 2005, and 2007. Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Deepwater CTD cast information is presented in Chapter 3: "Archipelagic Comparisons."

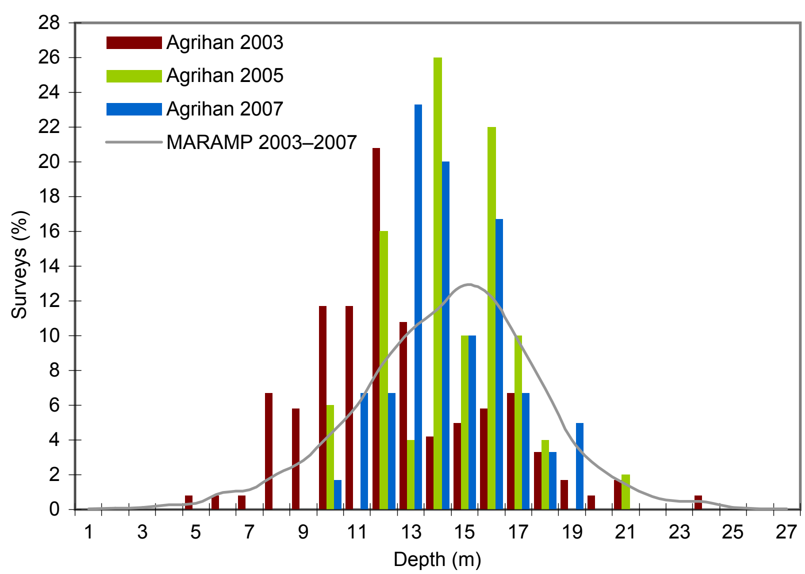
Observation Type	Year						
Instruments	2003	2005		2007		2009	Lost
	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	
STR	1	1	1	1	1	1	–
CTD Casts	**2003**	**2005**		**2007**			**Total**
Shallow-water Casts	15	14		15			44
Deepwater Casts	–	3		1			4
Water Samples		**2005**		**2007**			**Total**
		–		3			3

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Agrihan were collected using (1) subsurface temperature recorders (STR) designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water samples were collected during 2007 (see Chapter 2: "Methods and Operational Background," Section 2.3: "Oceanography and Water Quality"). A summary of deployed instruments and collection activities is provided in Table 14.2b, and results are discussed in Section: 14.4: "Oceanography and Water Quality."

Towed-diver Surveys: Depths

Figures 14.2b and c illustrate the locations and depths of towed-diver-survey tracks around Agrihan and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

Figure 14.2b. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005 and 2007.



During MARAMP 2003, 12 towed-diver surveys were conducted along the forereef slopes around Agrihan (Figs. 14.2b and c, top panel). The mean depth of all survey segments was 12.6 m (SD 1.7), and the mean depths of individual surveys ranged from 10.2 m (SD 2.8) to 15.4 m (SD 4).

During MARAMP 2005, 5 towed-diver surveys were conducted along the forereef slopes around parts of Agrihan (Figs. 14.2b and c, middle panel). The mean depth of all survey segments was 14.6 m (SD 0.9), and the mean depths of individual surveys ranged from 13.6 m (SD 2.6) to 15.6 m (SD 1.8).

During MARAMP 2007, 6 towed-diver surveys were conducted along the forereef slopes around most of Agrihan (Figs. 14.2b and c, bottom panel). The mean depth of all survey segments was 14.4 m (SD 1.5), and the mean depths of individual surveys ranged from 12.4 m (SD 2.7) to 16.1 m (SD 2.8).

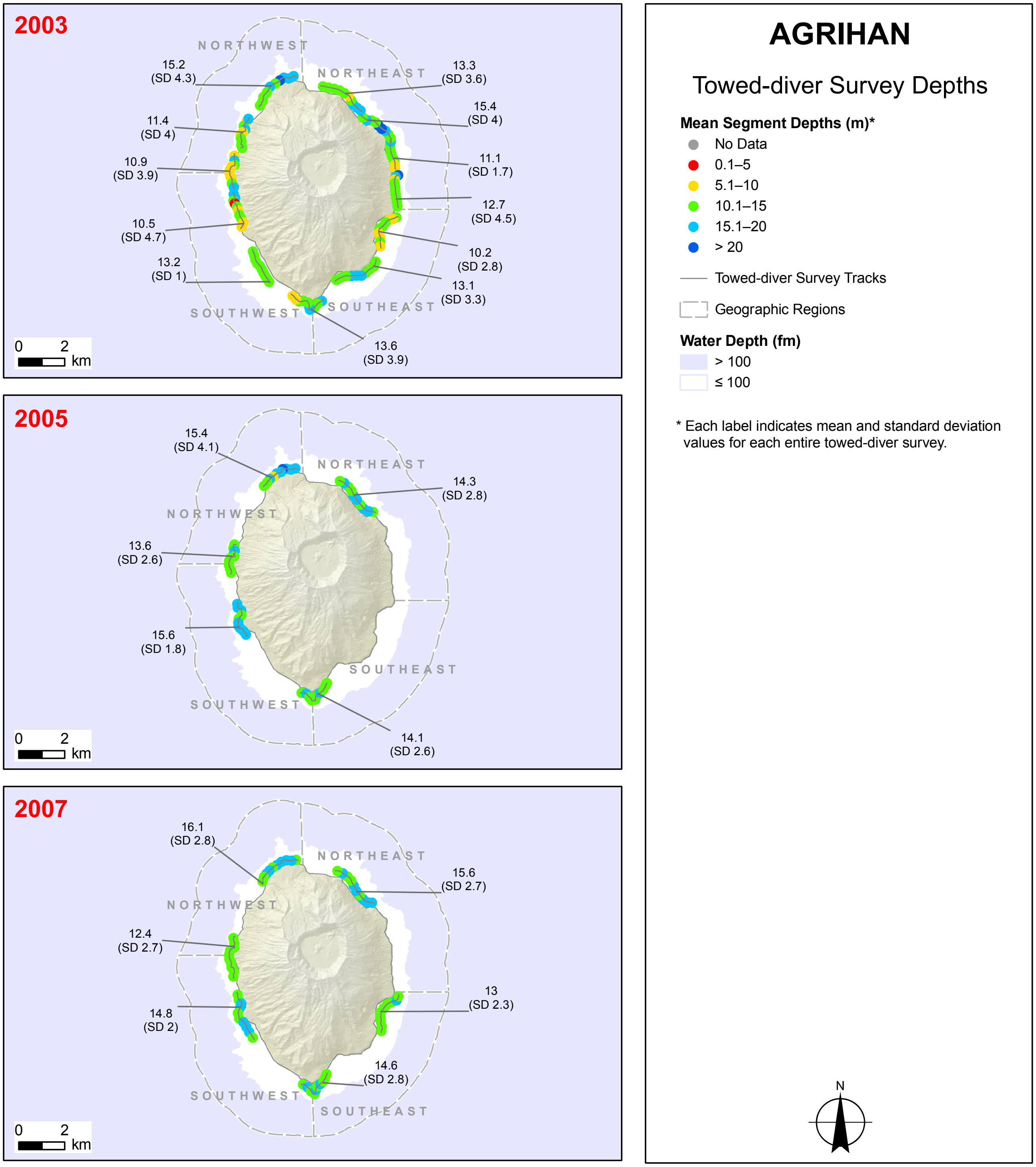


Figure 14.2c. Depths and tracks of towed-diver surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

14.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Agrihan were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products from depths of 20–2100 m with almost complete coverage around Agrihan. Optical validation and benthic characterization were conducted in depths of 5–165 m by a combination of diver observation, video analysis, and still image analysis.

14.3.1 Acoustic Mapping

Multibeam bathymetry and backscatter imagery (Fig. 14.3.1a) collected by the Coral Reef Ecosystem Division (CRED) around Agrihan and Pagan during MARAMP 2007 encompasses an area of 2511 km^2.

The multibeam data collected in the deep waters (> 100 m) around Agrihan reveal steep-sided volcanic flanks incised on all sides by submarine channels and canyons (Fig. 14.3.1a, top panel). Blocky material at depths > 500 m primarily was the result of mass wasting (the movement of soil and surface materials by gravity), although some of the larger mounds also may be volcanic in origin. For example, the bathymetric high located ~ 4 km northwest of this island is conical, has a circular peak that reaches a depth of ~ 480 m, and may be a separate volcanic edifice formed on the submarine flanks of Agrihan.

Low-resolution backscatter data acquired around Agrihan show intensity variations that relate to type of seafloor substrate (Fig. 14.3.1a, bottom panel). High-intensity backscatter characterizes the blocks of material present on the submarine flanks and the shallow seafloor adjacent to this island, suggesting areas composed of hard substrate. Around southern

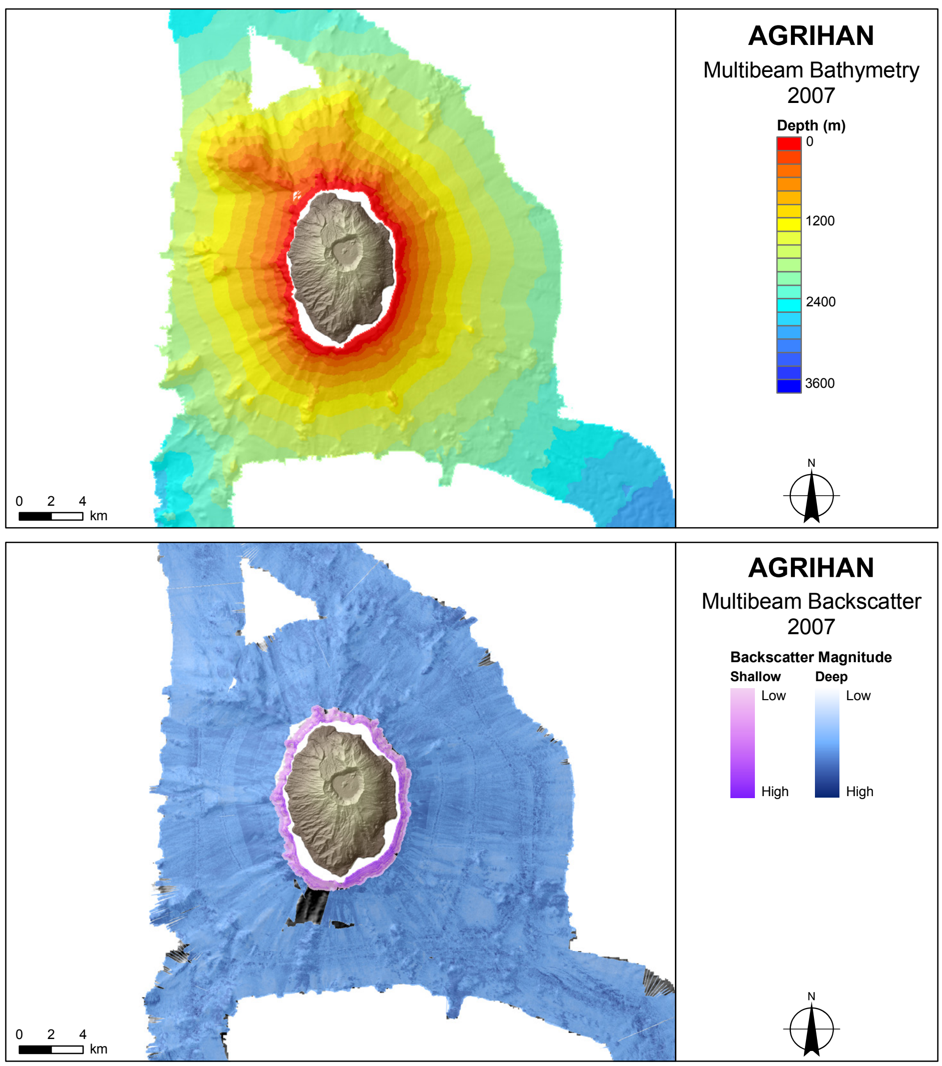


Figure 14.3.1a. Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Agrihan during MARAMP 2007 in depths of 20–2810 m. Shallow backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and deep backscatter data (shown in blue) were collected using a 30-kHz Kongsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.

Agrihan, several large, low-intensity backscatter areas are present between ridges that radiate away from the volcano and on lower angle portions of the submarine flanks. These areas are sandy or composed of unconsolidated material. Additionally, alternating bands of high and low backscatter are present on the Agrihan flanks and characteristic of slopes incised by canyons and channels.

High-resolution Multibeam Bathymetry and Derivatives

High-resolution multibeam data collected in nearshore (depths of 0–800 m) waters around Agrihan were combined into a grid at 10-m resolution to allow for identification of fine-scaled features (Fig. 14.3.1b). These high-resolution data also have been used to derive maps showing slope (Fig. 14.3.1c), rugosity (Fig. 14.3.1d), and Bathymetric Position Index (BPI) zones (Fig. 14.3.1e). Together, these maps provide layers of information to characterize the benthic habitats around Agrihan.

The submarine character of Agrihan is fairly consistent within the northeast, southeast, and southwest regions. The slope, BPI, and rugosity maps reveal a flat, low-rugosity area at the shallowest depths (30–40 m) mapped with multibeam within these regions, particularly in the southeast region where a narrow platform is revealed. Below this flat area, the moderately sloping seabed descends to 120–140 m, where very steep slopes of > 50° are observed. The flanks below a depth of 140 m have fairly uniform, low- to moderate-rugosity slopes of ~ 15°–20°. Steep-sided ridges, highlighted by the BPI analysis, incise these flanks (Fig. 14.3.1e).

No shallow, flat areas were observed northwest of Agrihan, but, otherwise, the seafloor is very similar to the other regions. A broad ridge extending for more than 4 km in a northwesterly direction is an extension of the lava flow shown northwest of the crater in the digital elevation model for this island. This uneven topography, shown in the low-resolution multibeam bathymetry (Fig. 14.3.1a, top panel), results from this ridge not having a distinct, linear crest but instead having a number of smaller, sinuous crests. Additionally, at the end of this ridge, a small (~ 300 m in diameter) crater can be seen on both the high-resolution bathymetry and slope maps (Figs. 14.3.1b and c). Rugosity data suggest that the top of this ridge is fairly smooth (Fig. 14.3.1d), and some flat areas are shown in the slope map and BPI analysis (Figs. 14.3.1c and e). The ridge crest and narrow platform southeast of Agrihan are the only flat zones shown in the BPI analysis within the entire mapped area, which is otherwise dominated by slope zones with narrow crests and depressions associated with the many ridges.

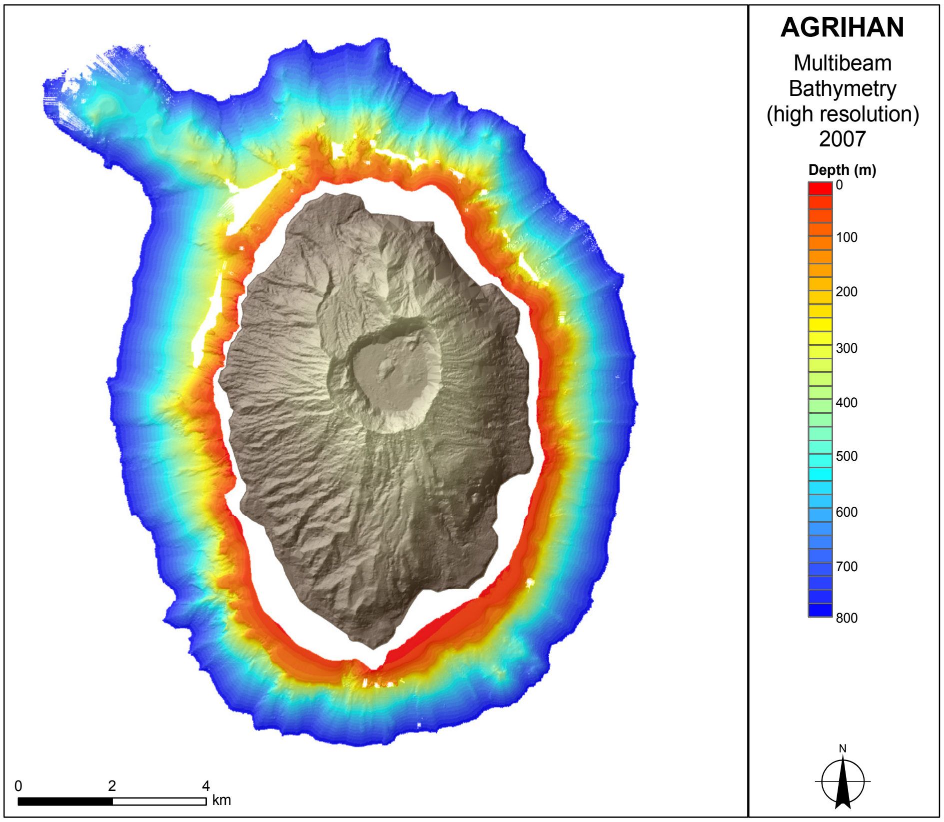


Figure 14.3.1b. High-resolution multibeam bathymetry collected around Agrihan during MARAMP 2007. This 10-m bathymetry grid has been clipped at 800 m and is used as the basis for slope, rugosity, and BPI derivatives.

Figure 14.3.1c. Slope (°) of 10-m bathymetric grid around Agrihan. Derived from data collected in 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.

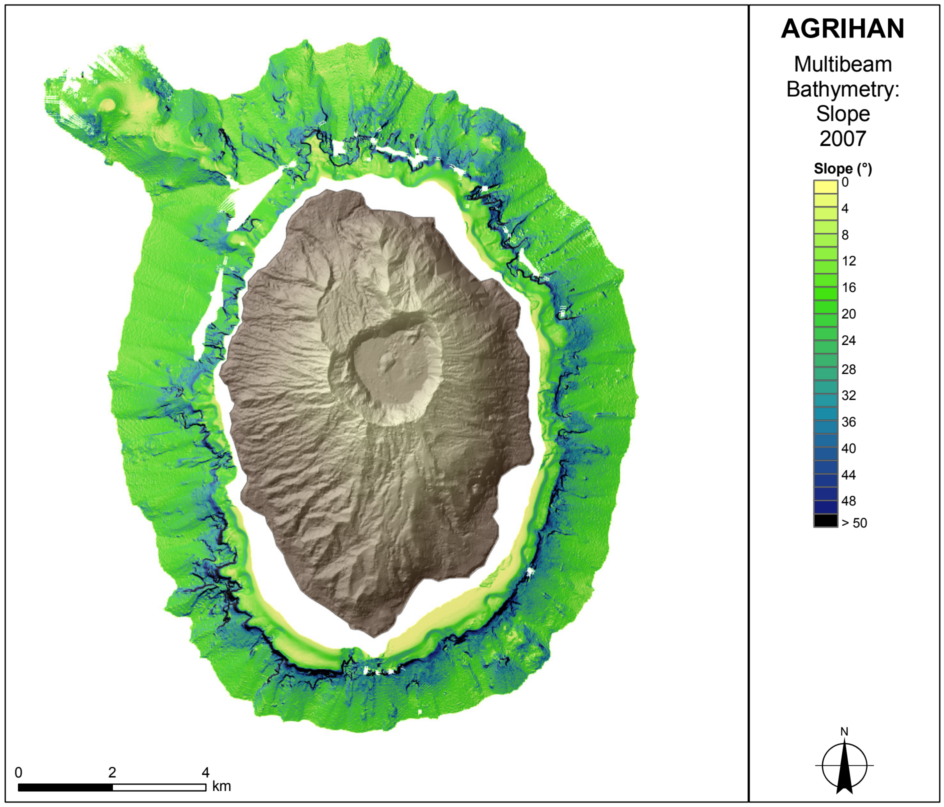
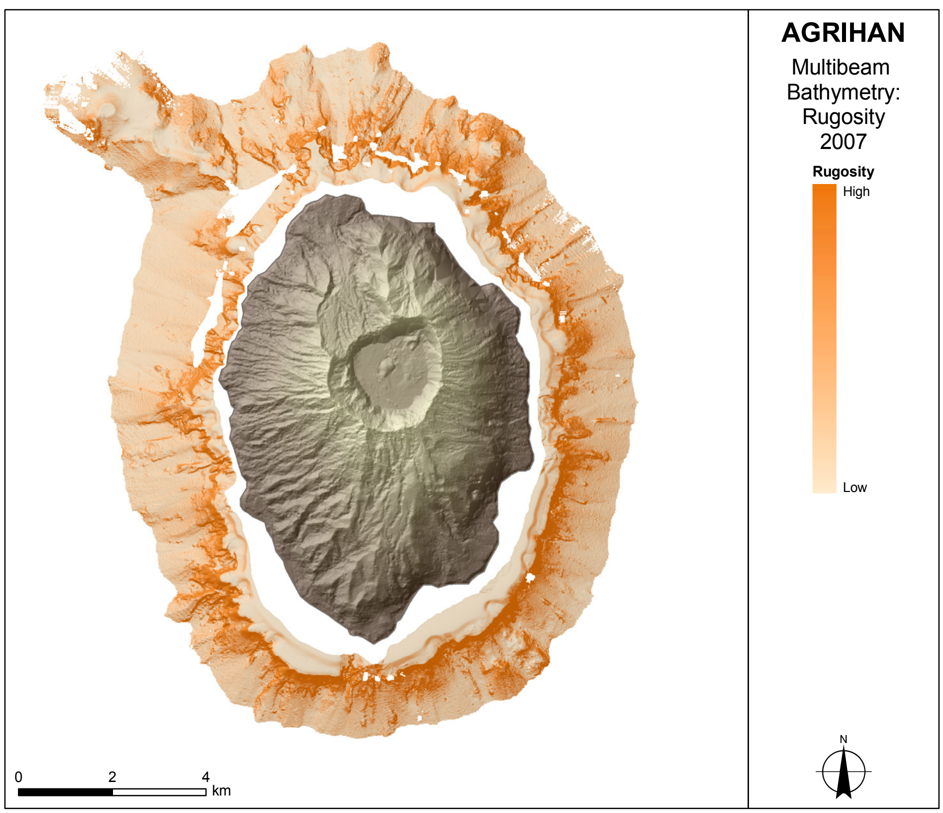


Figure 14.3.1d. Rugosity of 10-m bathymetric grid around Agrihan. Derived from data collected in 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.



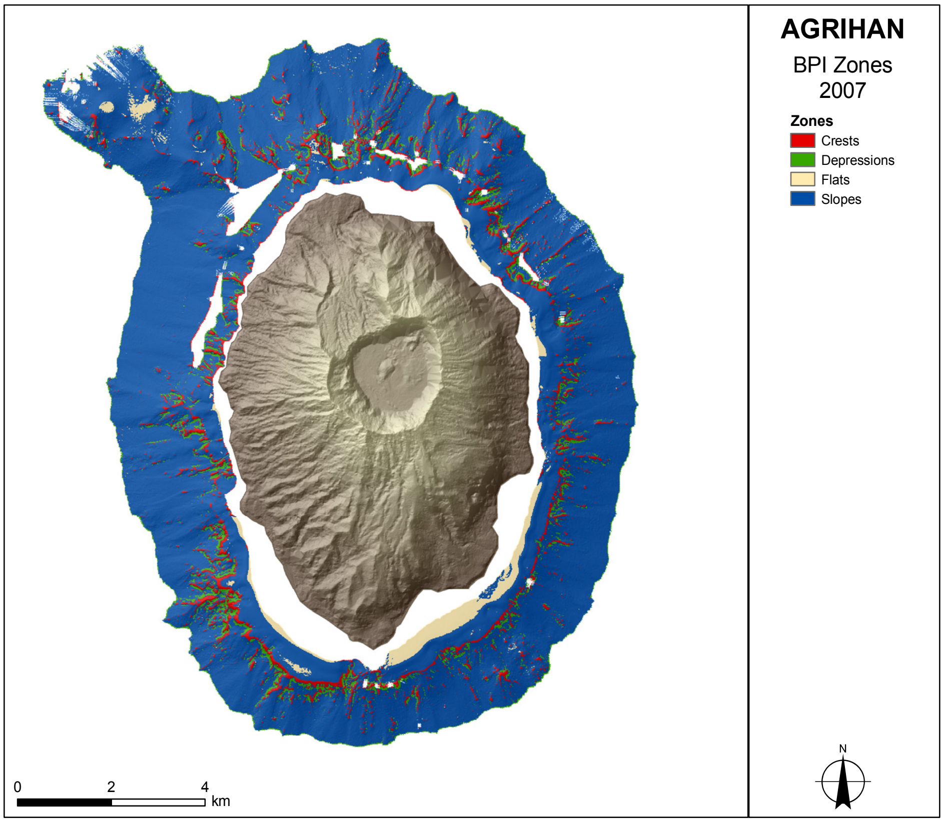


Figure 14.3.1e. BPI zones of 10-m bathymetric grid around Agrihan derived from data collected in 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—were used in this analysis.

High-resolution Multibeam Backscatter and Derivatives

The high-resolution backscatter data acquired around Agrihan has some noticeable artifacts, such as gaps in data between inner and outer swaths, but in general the data shows distinct patterns in the variation of backscatter intensity around this island that are strongly linked to the topography (Fig. 14 3.1f). These data also were used in an unsupervised classification (see Chapter 2: "Methods and Operational Background," Section 2.2.2: "Acoustic Mapping") of the substrate to produce hard–soft substrate maps (Fig. 14 3.1g). Although the hard–soft analysis is a useful tool to help interpret the seabed character around Agrihan, insufficient optical ground truth data are available to calculate classification accuracy. Nevertheless, the hard–soft analysis provides some indication of the distribution of different substrate types around this island.

High-intensity backscatter values were observed on the shallow platforms around the northeast, southeast, and southwest coasts of Agrihan, and these areas were classified as hard substrate. On the flanks below, high- and low-intensity backscatter correlated with the presence of ridges and channels. These observations were confirmed by the hard–soft analysis, which classified the ridges as having hard substrates and the channels in between as having soft substrates. Around northwest Agrihan, no shallow platform and fewer areas of high-intensity backscatter are present. High-intensity backscatter characterizes the tops of several short ridges, and they are classified as hard substrates. Seafloor with low-intensity backscatter, classified as soft substrate, is present in channels on the flanks, suggesting down-slope sediment transport.

Figure 14.3.1f. Gridded, high-resolution, multibeam backscatter data (grid cell size: 1 m) collected around Agrihan during MARAMP 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.

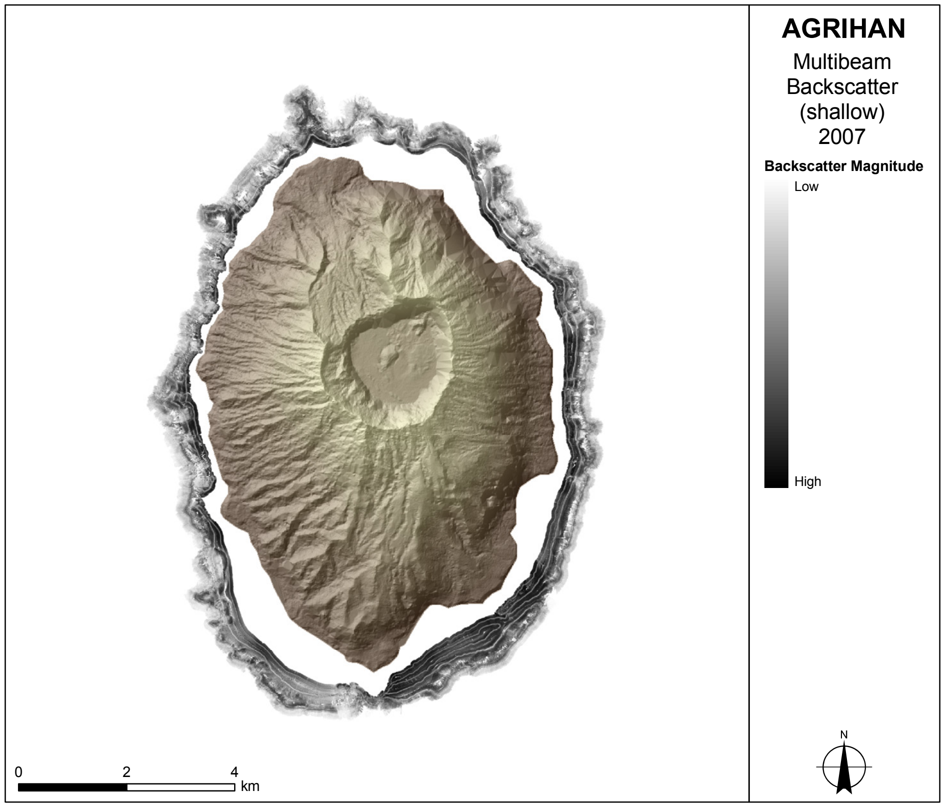
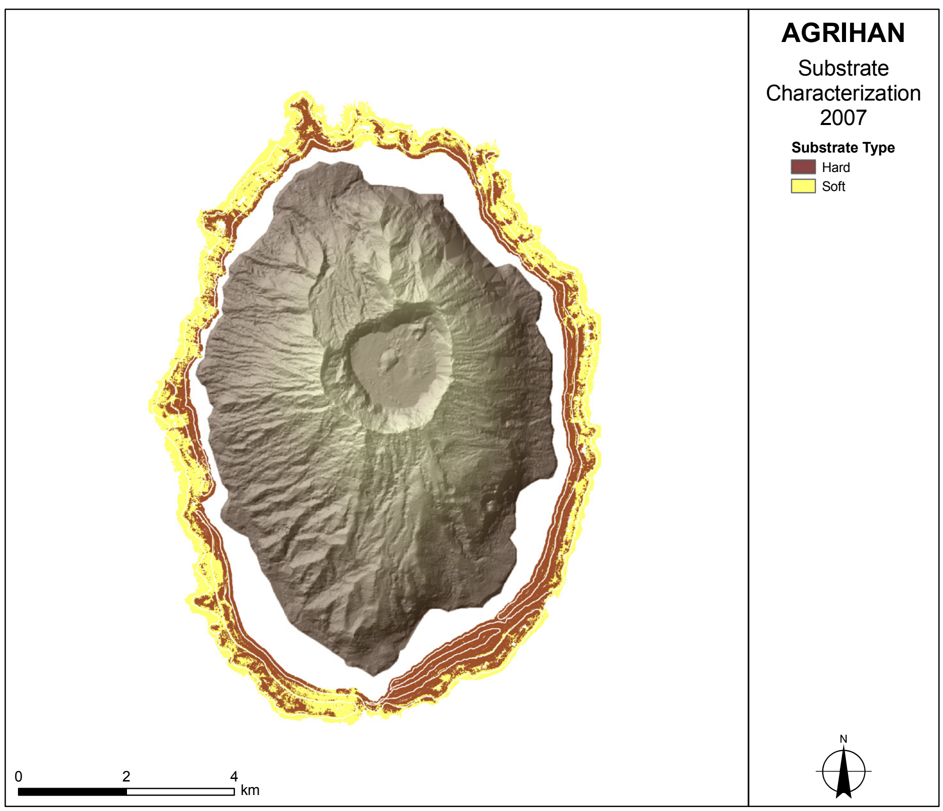


Figure 14.3.1g. Hard and soft substrates (grid cell size: 5 m) at depths of < 350 m based upon an unsupervised classification of multibeam bathymetry and backscatter data acquired around Agrihan between 2003 and 2007. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.



14.3.2 Optical Validation

During MARAMP 2003, 8 TOAD optical-validation surveys were conducted around Agrihan, covering a distance of ~ 6 km at depths of 1–220 m (Fig. 14.3.2a). Subsequent analyses of video acquired from these surveys provided estimates of the percentages of sand cover and live coral cover.

Covering a distance of ~ 45 km at depths of 5–24 m, 23 towed-diver optical-validation surveys of forereef habitats were conducted around Agrihan during MARAMP 2003, 2005, and 2007. At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

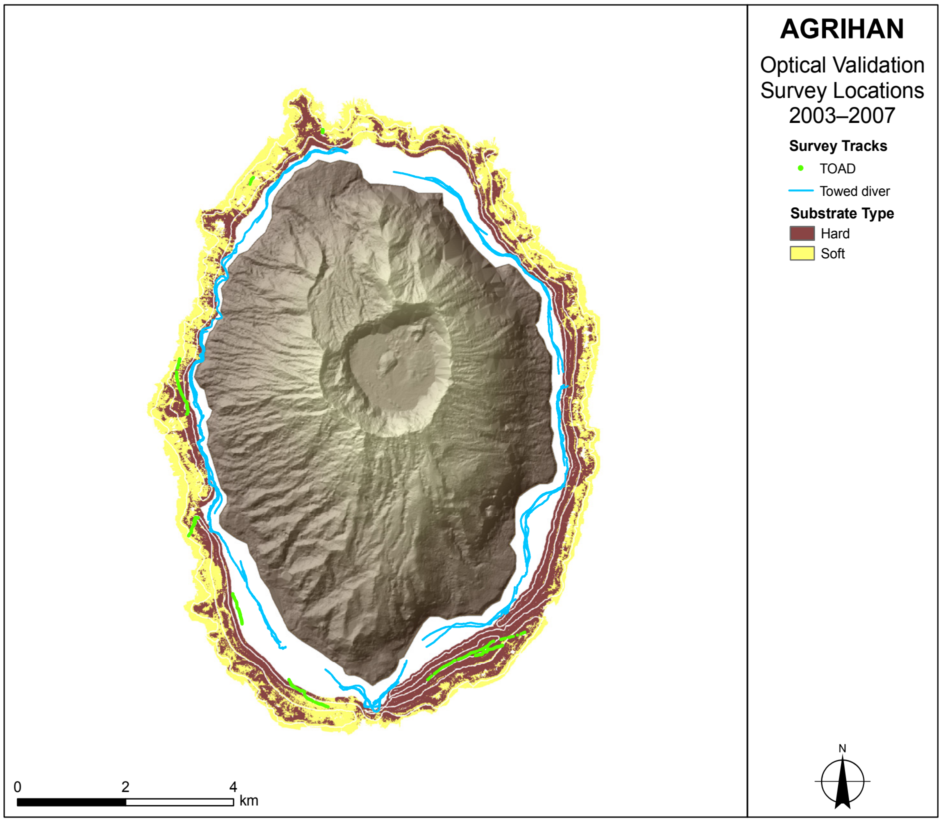


Figure 14.3.2a. Towed-diver tracks from surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007 and TOAD camera-sled tracks for MARAMP 2003. Survey tracks are displayed over the multibeam hard–soft substrate map. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.

14.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Agrihan are discussed in this section. Around west and northwest Agrihan, towed-diver surveys recorded sand cover (Fig.14.3.3a, top panel) that was generally low (< 10%) and habitat of medium to high complexity (Fig.14.3.3a, middle panel**)**. In this area, observed cover of live hard corals (Fig.14.3.3a, bottom panel) also was fairly low at 5.1%–20%, although a higher level of coral cover was recorded adjacent to the onshore lava flow, clearly seen on the island topography northwest of the main caldera. This area, based on towed-diver surveys, was characterized predominantly as continuous reef and ridges with occasional boulder fields. Farther offshore from the lava flow, analyses of video footage obtained from TOAD surveys suggested hard substrates, although no live coral cover was observed. Hard–soft analysis classified this area as soft substrates. This apparent discrepancy could be caused by the different scale at which the TOAD video and bathymetry data are used, with the hard–soft analysis based on a 5-m grid providing a broader picture of the nature of the substrate and the TOAD video imaging a small area of seafloor. On a short ridge north of Agrihan, analyses of video footage from another TOAD survey, revealed a seabed characterized by 100% sand cover, corresponding to an area of soft substrate identified by the hard–soft classification. West of Agrihan, for an area that was mainly classified as hard substrate by the hard–soft analysis, analyses of video footage from a TOAD survey suggested a mixed substrate with a large section of 100% sand cover. This apparent contradiction may be a result of the sand observed on the video being a thin veneer overlying the hard substrates suggested by the acoustic signature.

Northeast of Agrihan, low sand cover < 20% was observed during towed-diver surveys in an area described as including pavement, boulders on sand, and rocky ridges. Recorded habitat complexity was medium-low to high. In the southern half of the northeast region, an area of higher live coral cover of 10.1%–50% was observed adjacent to a flatter area observed on the island topography.

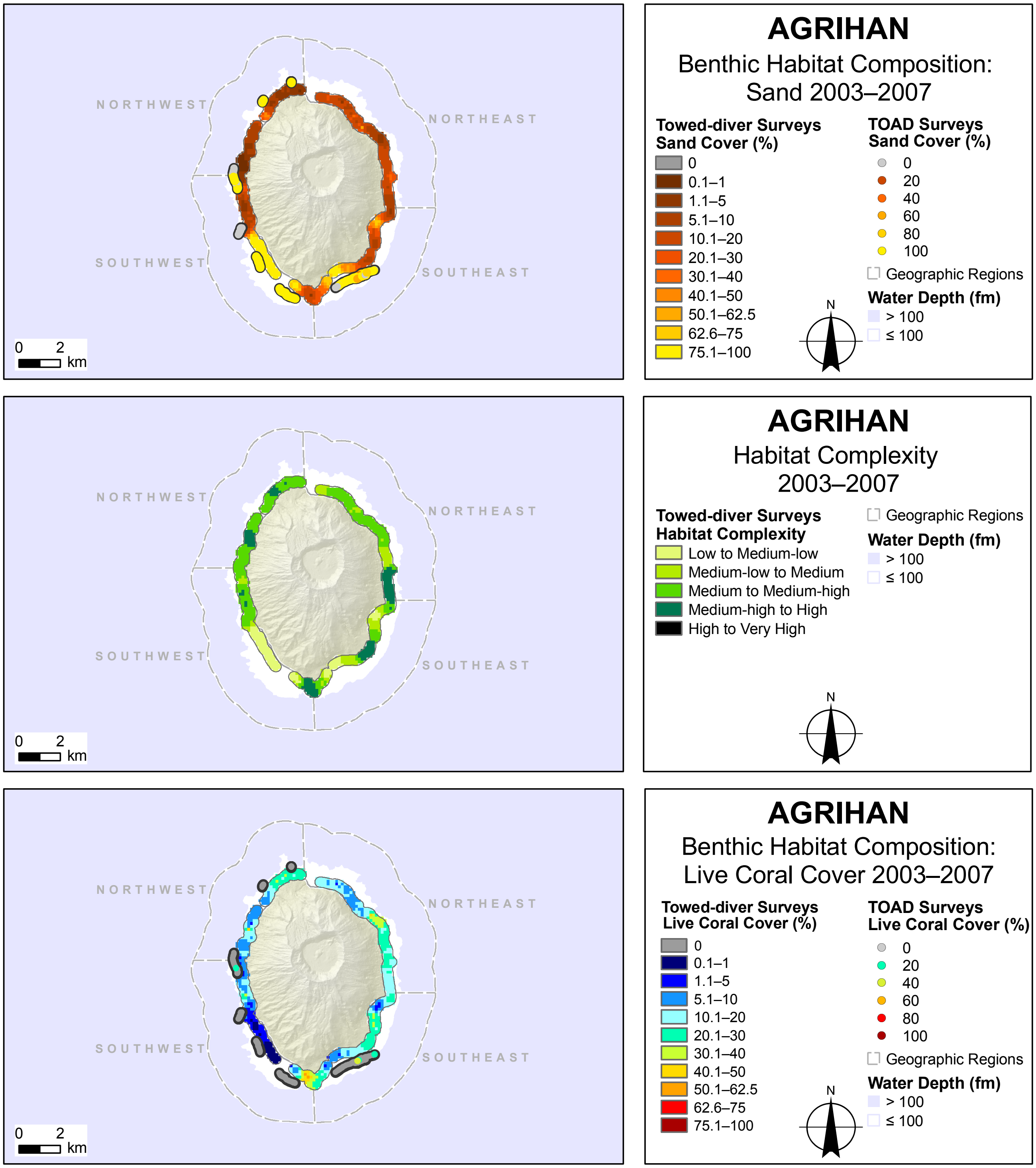


Figure 14.3.3a. Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) live-hard-coral cover (%) from towed-diver surveys of forereef habitats conducted and analyses of TOAD video collected around Agrihan during MARAMP 2003, 2005, and 2007.

Within the southeast region, benthic habitat composition was more variable. Patches of low complexity, sandy habitat supporting low cover of live hard corals were observed within the wide bays on this coastline, with sand cover as high as 75.1%–100% and live coral cover < 10% from towed-diver surveys. The areas between these patches were characterized by more complex habitats, with lower sand cover (< 30%) and higher live coral cover (10.1%–62.5%). These areas were described during towed-diver surveys in some locations as medium-relief, spur-and-groove habitats. In the southeast region, analyses of video footage obtained during 2 adjacent TOAD surveys conducted at depths of 25–70 m revealed that the substrate was primarily sandy, with a majority of analyzed video frames revealing sand cover of 80.1%–100% and a few frames suggesting small amounts of live corals with cover of 20.1%–40%. West of the southern point of Agrihan, seabed composed of 100% sand, again, with no benthic fauna was revealed during analyses of TOAD video acquired during a TOAD survey conducted at depths of 30–45 m.

Southwest of Agrihan, towed-diver surveys characterized a large area as habitat of low to medium-low complexity and sand substrates, with sand cover of 75.1%–100% sand cover and very low live coral cover < 5%. In adjacent deeper waters, analyses of TOAD video collected also revealed substrates with observed sand cover of 100%.

14.4 Oceanography and Water Quality

14.4.1 Hydrographic Data

2003 Spatial Surveys

During MARAMP 2003, 15 shallow-water CTD casts were conducted in nearshore waters around the island of Agrihan over the period of August 26–September 6. Temperature, salinity, density, and beam transmission values varied both spatially and vertically around this island. Spatial comparisons of water properties at a depth of 10 m suggest small differences in temperature (0.2°C), salinity (0.2 psu), density (0.1 kg m^{-3}), and beam transmission (< 1%) values; however, temperature, salinity, density, and beam transmission values were recorded at higher levels in the northwest and northeast regions than in the southwest and southeast regions (Fig. 14.4.1a). Vertical comparisons of CTD profiles reveal moderate differences in temperature (0.7°C), salinity (0.4 psu), density (0.4 kg m^{-3}), and beam transmission (2%) values (Fig. 14.4.1b). Marked intra-island differences in salinity values occurred, with recorded salinity higher in the northwest and northeast regions (casts 2–8) than in the 2 southern regions. Temperature values, however, did not show this same spatial pattern. Instead, temperature observations alternate around this island between well-mixed, nearly homogenous profiles and highly stratified profiles with warm waters overlying cooler waters. Beam transmission data appear to vary concurrently with salinity values, and density data show variability similar to temperature values. These differences in values could have resulted from temporal separation in sampling.

2005 Spatial Surveys

During MARAMP 2005, 14 shallow-water CTD casts were conducted in nearshore waters around Agrihan on September 15. Temperature, salinity, density, and beam transmission values varied both spatially and vertically around this island. Spatial comparisons of water properties at a depth of 10 m suggest little variability around Agrihan with small ranges in temperature (0.2°C), salinity (0.04 psu), density (0.1 kg m^{-3}), and beam transmission (< 1%) values; however, recorded temperatures were slightly warmer in the southeast and southwest regions than in the northeast and northwest regions, indicating small intra-island differences (Fig. 14.4.1c). Vertical comparisons of CTD profiles reveal moderate ranges in temperature (0.4°C) and salinity (0.3 psu) values and slight ranges in density (0.2 kg m^{-3}) and beam transmission (1.1%) values. A shift in water properties occurred between casts 7 and 8 (Fig. 14.4.1d), with warm, well-mixed waters observed in the southeast and southwest regions (casts 8–14) and comparatively cooler, more saline waters in the northwest and northeast regions (casts 1–7).

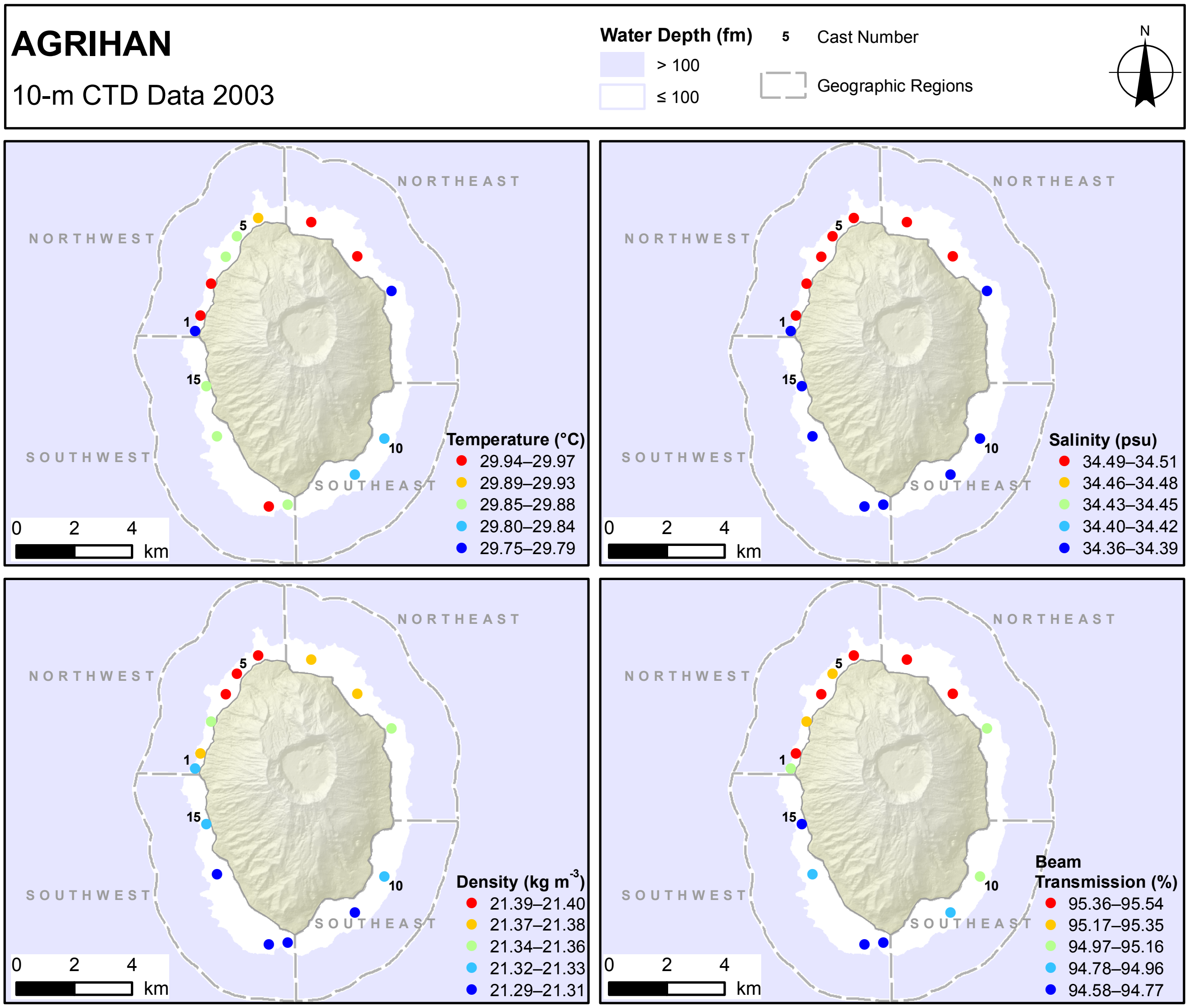
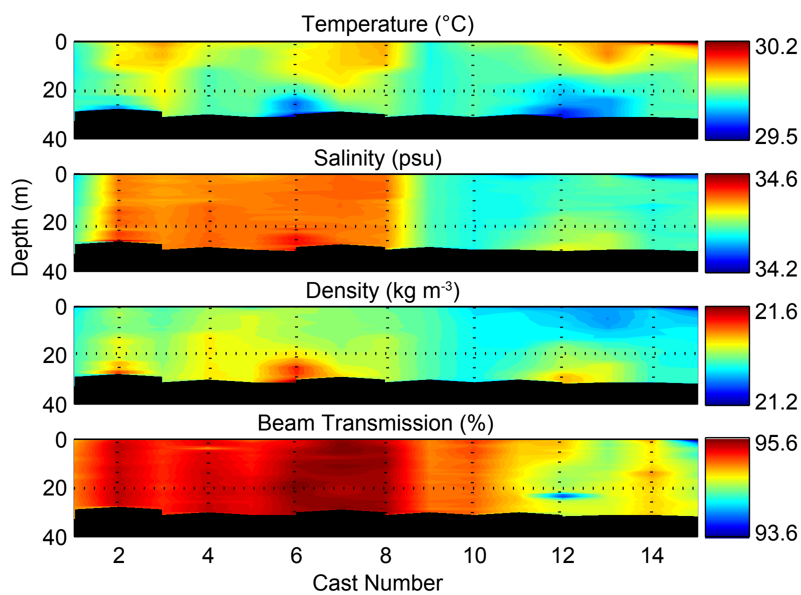


Figure 14.4.1a. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Agrihan during MARAMP 2003, with cast 9 done on August 26, casts 1 and 10–15 done on August 27, casts 7 and 8 done on September 5, and casts 2–6 done on September 6.

Figure 14.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Agrihan during MARAMP 2003, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–15 in a clockwise direction around Agrihan. Cast 9 was completed on August 26, casts 1 and 10–15 were done on August 27, casts 7 and 8 were done on September 5, and casts 2–6 were done on September 6. For cast locations and numbers around this island in 2003, see Figure 14.4.1a.



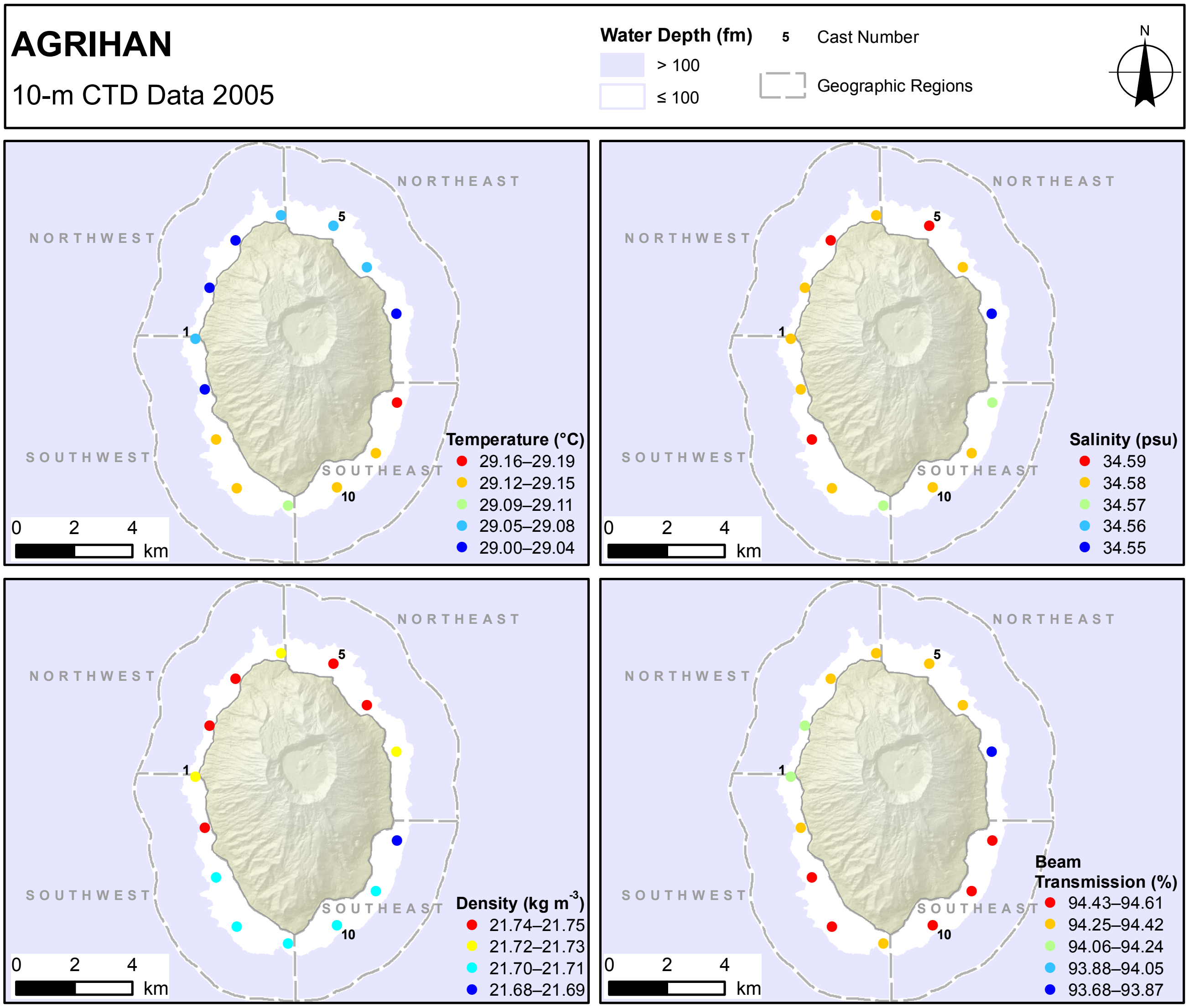


Figure 14.4.1c. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Agrihan on September 15 during MARAMP 2005.

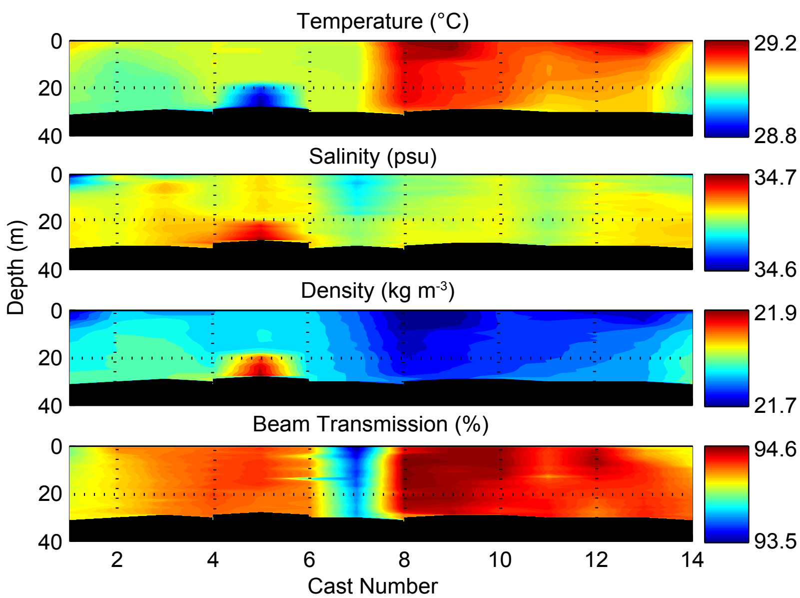


Figure 14.4.1d. Shallow-water CTD cast profiles to a 30-m depth around Agrihan on September 15 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–14 in a clockwise direction around Agrihan. For cast locations and numbers around this island in 2005, see Figure 14.4.1c.

2007 Spatial Surveys

During MARAMP 2007, 15 shallow-water CTD casts were conducted in nearshore waters around Agrihan on May 29. Temperature, salinity, density, and beam transmission values varied both spatially and vertically. Spatial comparisons of water properties at a depth of 10 m show little variability around this island; however, broad ranges in temperature (1.9°C) and density (0.7 kg m^{-3}) values were recorded as a result of a single cast (cast 11) in the southeast region (Fig. 14.4.1e). Vertical comparisons of CTD profiles reveal mostly well-mixed waters, although considerable ranges in temperature (3.2°C) density (1 kg m^{-3}) values combined with moderate ranges in salinity (0.2 psu) and beam transmission (1.4%) values were recorded (Fig. 14.4.1f). The large range in temperature values principally is a result of localized upwelling of deep waters in the southeast region (cast 11) and to a lesser extent in the northwest region (cast 2).

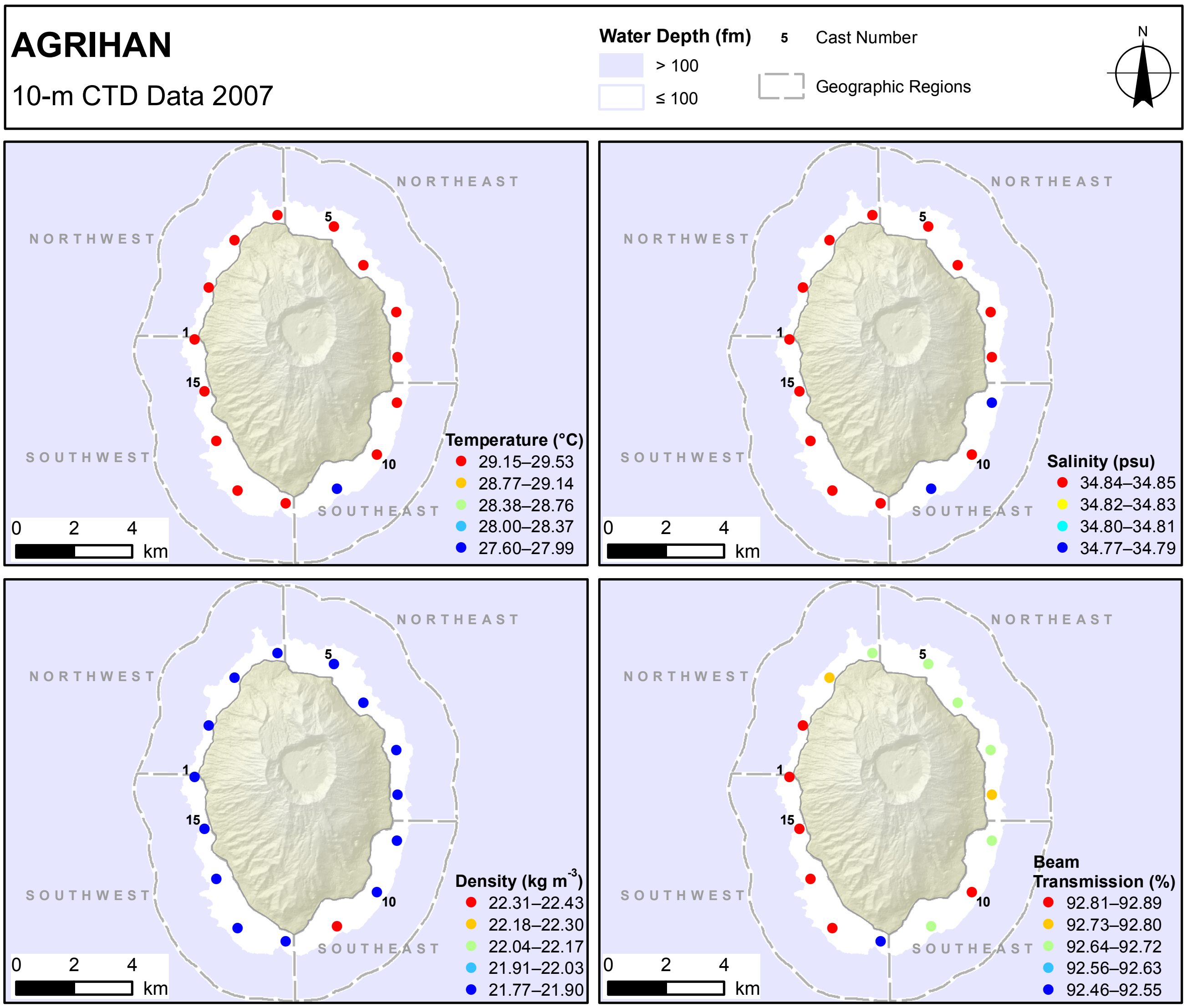


Figure 14.4.1e. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Agrihan on May 29 during MARAMP 2007.

Water samples were collected in concert with shallow-water CTD casts at 3 select locations at Agrihan in 2007 to assess water-quality conditions. The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.06–0.09 µg L^{-1}; total nitrogen (TN), 0.02–0.11 µM; nitrate (NO_3^-), 0.01–0.10 µM; nitrite (NO_2^-), 0.005–0.011 µM; phosphate (PO_4^{3-}), 0.01–0.02 µM; silicate [$Si(OH)_4$], 1.21–1.73 µM. The highest values of Chl-*a* were recorded in the northwest region, and the highest values of total nitrogen, nitrate, nitrite, and phosphate were all observed in the southwest region (Fig. 14.4.1g).

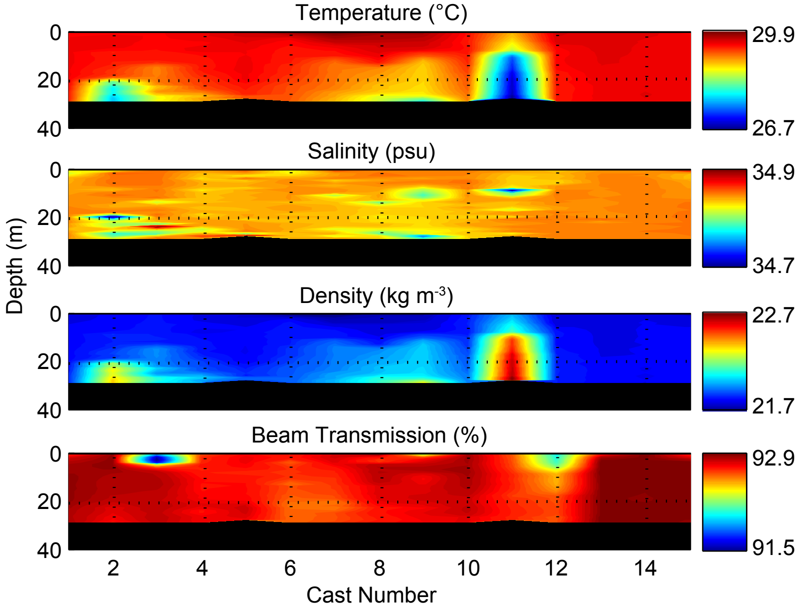


Figure 14.4.1f. Shallow-water CTD cast profiles to a 30-m depth around Agrihan on May 29 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–15 in a clockwise direction around Agrihan. For cast locations and numbers around this island in 2007, see Figure 14.4.1e.

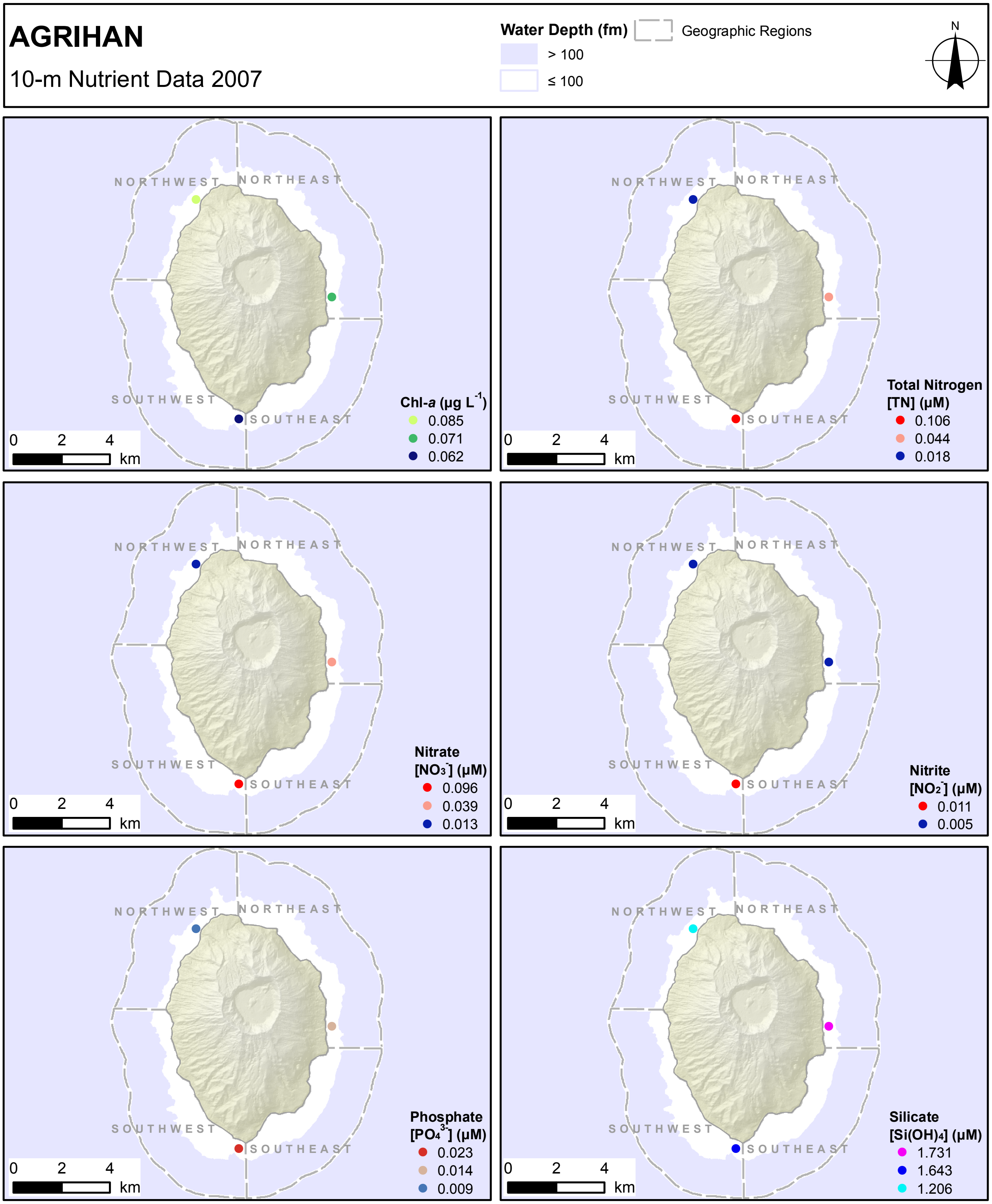


Figure 14.4.1g. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate, at a 10-m depth from water samples collected at Agrihan on May 29 during MARAMP 2007.

Temporal Comparison

Comparisons of shallow-water CTD data from MARAMP 2003, 2005, and 2007 suggested a dynamic physical oceanographic environment. During MARAMP 2003 and 2005 minimal spatial variability and moderate vertical variability were observed, and during MARAMP 2007 substantial spatial variability in water properties was recorded, although intra-island differences were entirely attributed to a single cast location in the southeast region with exceptionally cooler temperatures. Cold water (26.7°C; 3.2°C colder than surface waters) intrusions originating from below a depth of 30 m may be caused by upwelling or internal tide activity. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in May, and MARAMP 2003 and 2005 occurred in August and September. This change was made to avoid the typhoon season and reduce the probability of weather disruptions.

14.4.2 Time-series Observations

Between 2003 and 2007, one type of moored instrument was installed at Agrihan, a subsurface temperature recorder (STR), to collect time-series observations of a key oceanographic parameter influencing reef conditions. The location, depth, time frame, and other details about these deployments are provided in Figures 14.4.2a and b.

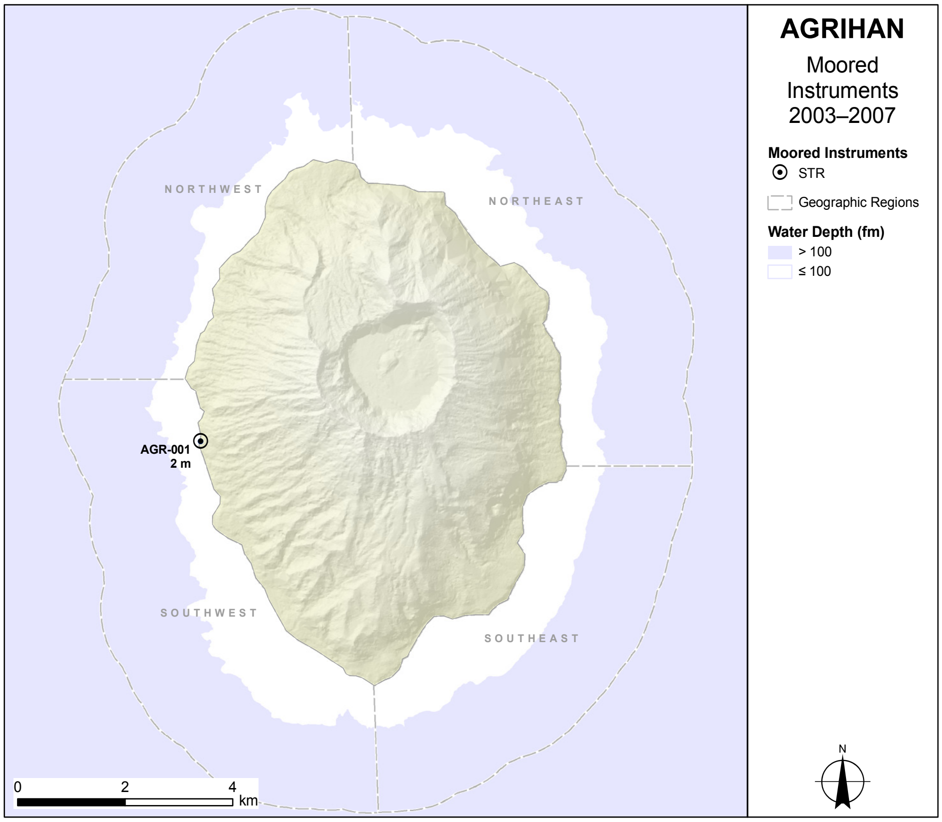


Figure 14.4.2a. Location and depth of the STRs deployed at Agrihan during MARAMP 2003, 2005, and 2007.

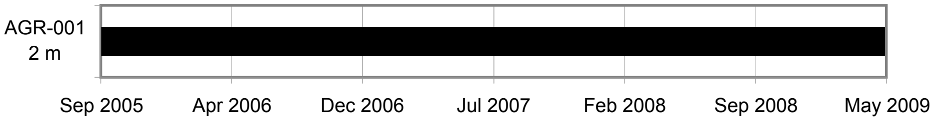


Figure 14.4.2b. Deployment timeline and depth of the STRs installed at Agrihan during the period from September 2005 to May 2009. A solid bar indicates the period for which temperature data were collected by a series of STRs that were deployed and retrieved at the mooring site AGR-001. For more information about deployments and retrievals, see Table 14.2b in Section 14.2: "Survey Effort."

A series of STRs were deployed at a depth of 2 m at the same location at Agrihan, mooring site AGR-001 in the southwest region. Data from these STRs for the period from September 2005 to June 2007 show seasonal temperature variability of ~ 4°C (Fig. 14.4.2c). Water temperatures reached 29°C–30°C during the months of June–October and fell to a low of ~ 27°C during the months of January–May. Temperature values exceeded the coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean, for the region in September 2006; however, the duration of this event was less than 1 d. Diurnal temperature fluctuations were ~ 0.25°C throughout this time series.

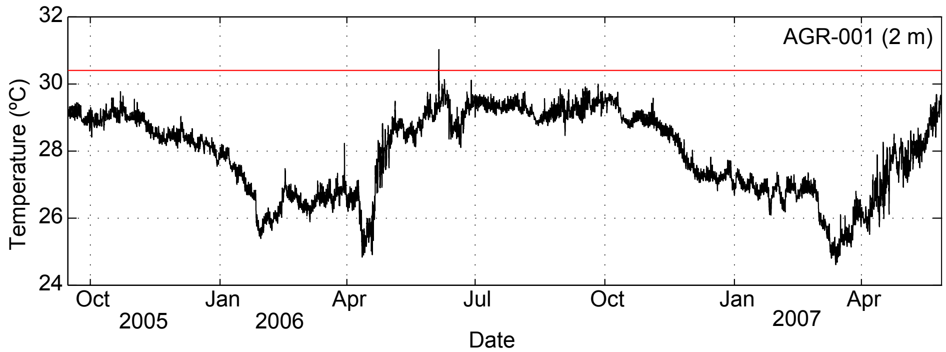


Figure 14.4.2c. Time-series observations of temperature over the period between September 2005 and June 2007 collected from 1 STR deployed in the southwest region at a depth of 2 m (see Figure 14.4.2a for mooring location). The red line indicates the coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.

14.4.3 Wave Watch III Climatology

Seasonal wave climatology for Agrihan (Fig. 14.4.3a) was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008, and seasons were selected to elucidate waves generated by typhoons, which most frequently occur between the period of August–December (for information about the Wave Watch III model, see Chapter 2: "Methods and Operational Background," Section 2.3.7: "Satellite Remote Sensing and Ocean Modeling"). In terms of consistency, the wave regime during this period was dominated by trade wind swells characterized by frequent (> 25 d per season), short-period (8–10 s), relatively small (2–3 m) wave events originating from the east (90°). Superimposed with these short-period swells were large (> 4 m), long-period (12–16 s) wave events principally from the south (180°), although they could originate from a broad directional source (150°–210°). These large, episodic waves primarily were generated by typhoons and occurred on annual to interannual time scales. Additionally, infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–3.5 m) occurred from the west and southwest (240°–270°) and probably were associated with episodic storms. Similar to the wave regime during typhoon season, the wave climate during the period of February–June (outside the typhoon season) was also characterized by frequent (> 30 d per season), short-period (~ 8 s) trade wind swells with relatively small wave heights (~ 2 m) originating from the east. Infrequent (< 5 d per season), long-period (12–14 s) swells with slightly larger wave heights (~ 3 m) also occurred during this period and originated from the southwest (240°) and the northwest (330°).

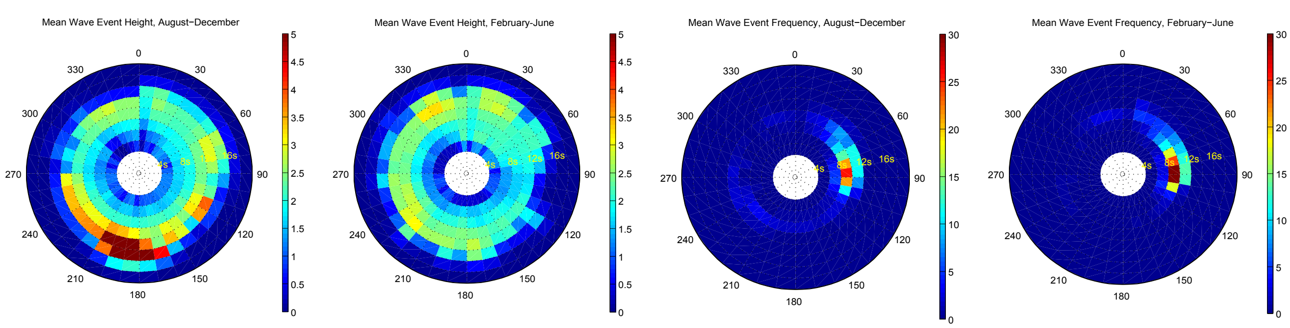


Figure 14.4.3a. NOAA Wave Watch III directional wave climatology for Agrihan from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box (1° × 1°) centered on Agrihan (18° N, 145° E). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occurred in each season, indicated by color scale; for example, if the color indicates 30, then, on average, the condition occurred during 30 of the 150 days of that season.

14.5 Corals and Coral Disease

14.5.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats around the island of Agrihan was 16% (SE 1.3). Coral cover was higher in the east regions than in the west regions (Fig. 14.5.1a, top panel). Localized areas of high coral cover were observed in the southwest region with a mean of 56% for 4 survey segments, in the northeast region with a mean of 34% for 7 segments, and in the southeast region with a mean of 35% for 6 segments.

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats at Agrihan was 15% (SE 2.1). Surveys in 2005 were limited to one day, resulting in partial spatial coverage compared to 2003. Coral cover was highest along the southern point of this island with a mean of 33% for 8 survey segments (Fig. 14.5.1a, middle panel). Towed divers recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"). Overall, 5.3% (SE 2.4) of coral cover observed on forereef habitats at Agrihan appeared stressed. The occurrence of stressed-coral cover was low for the majority of areas surveyed at this island, except the northeast region (Fig. 14.5.1a, middle panel), where divers noted predation by crown-of-thorns seastars (*Acanthaster planci*). For more information about crown-of-thorns seastar (COTS) observations at Agrihan, see Section 14.7.1: "Benthic Macroinvertebrate Surveys."

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats at Agrihan was 14% (SE 1.7). As was the case in 2005, surveys were limited to one day, resulting in partial spatial coverage compared to 2003. Coral cover was highest along the southern coastline of this island with a mean of 38% for 4 survey segments and in the northwest region with a mean of 31% for 7 segments (Fig. 14.5.1a, bottom panel). Overall, 1.5% (SE 0.4) of coral cover observed on forereef habitats around Agrihan appeared stressed in 2007. The occurrence of stressed-coral cover was low for the majority of areas surveyed around this island, with elevated levels of stressed-coral cover recorded in 2 areas. In the northeast region, divers noted the presence of COTS and predation scars on corals (Fig. 14.5.1a, bottom panel), and, in the southwest region, divers observed high numbers of COTS (> 100 individuals) and widespread predation scars during a safety stop at the end of a survey.

During MARAMP 2003, 4 REA benthic surveys using the quadrat method on forereef habitats at Agrihan documented 540 coral colonies within a total survey area of 15 m^2. Site-specific colony density ranged from 29.9 to 45.9 colonies m^{-2} with an overall sample mean of 36 colonies m^{-2} (SE 3.6). The highest colony density was recorded at REA site AGR-02 in the southwest region, and the lowest colony density was observed at AGR-04 in the northwest region (Fig. 14.5.1.b, top panel).

During MARAMP 2005, 3 REA benthic surveys using the quadrat method on forereef habitats at Agrihan documented 491 coral colonies within a total survey area of 12 m^2. Site-specific colony density ranged from 14.8 to 59.3 colonies m^{-2}, with an overall sample mean of 40.9 colonies m^{-2} (SE 13.4). The highest colony density was recorded at AGR-02 in the southwest region, and the lowest colony density was observed at AGR-06, farther north in the southwest region (Fig. 14.5.1b, middle panel).

During MARAMP 2007, 3 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats at Agrihan. Site-specific estimates of live-hard-coral cover from these surveys ranged from 17.7% to 38.2%, with an overall sample mean of 30.7% (SE 6.6). Live coral cover was highest at AGR-02 in the southwest region and lowest at AGR-01 in the southeast region (Fig. 14.5.1b, bottom panel).

During MARAMP 2007, 3 REA benthic surveys using the quadrat method on forereef habitats at Agrihan documented 612 coral colonies within a total survey area of 12 m^2. Site-specific colony density ranged from 40.5 to 56.5 colonies m^{-2}, with an overall sample mean of 51 colonies m^{-2} (SE 5.3). The highest colony density was recorded at both AGR-04 in the northwest region and AGR-02 in the southwest region (Fig. 14.5.1b, bottom panel).

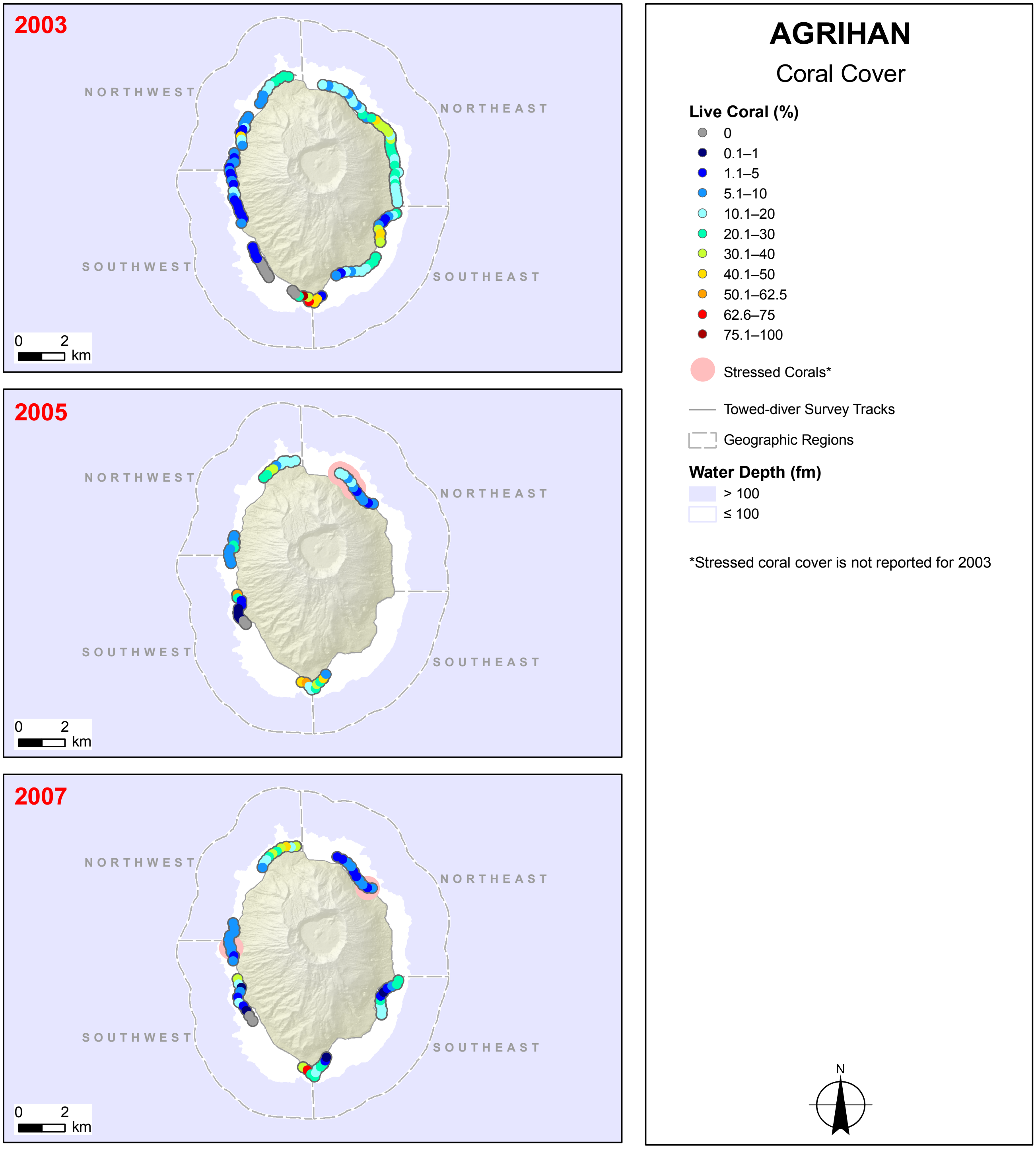


Figure 14.5.1a. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m^2). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005 and 2007.

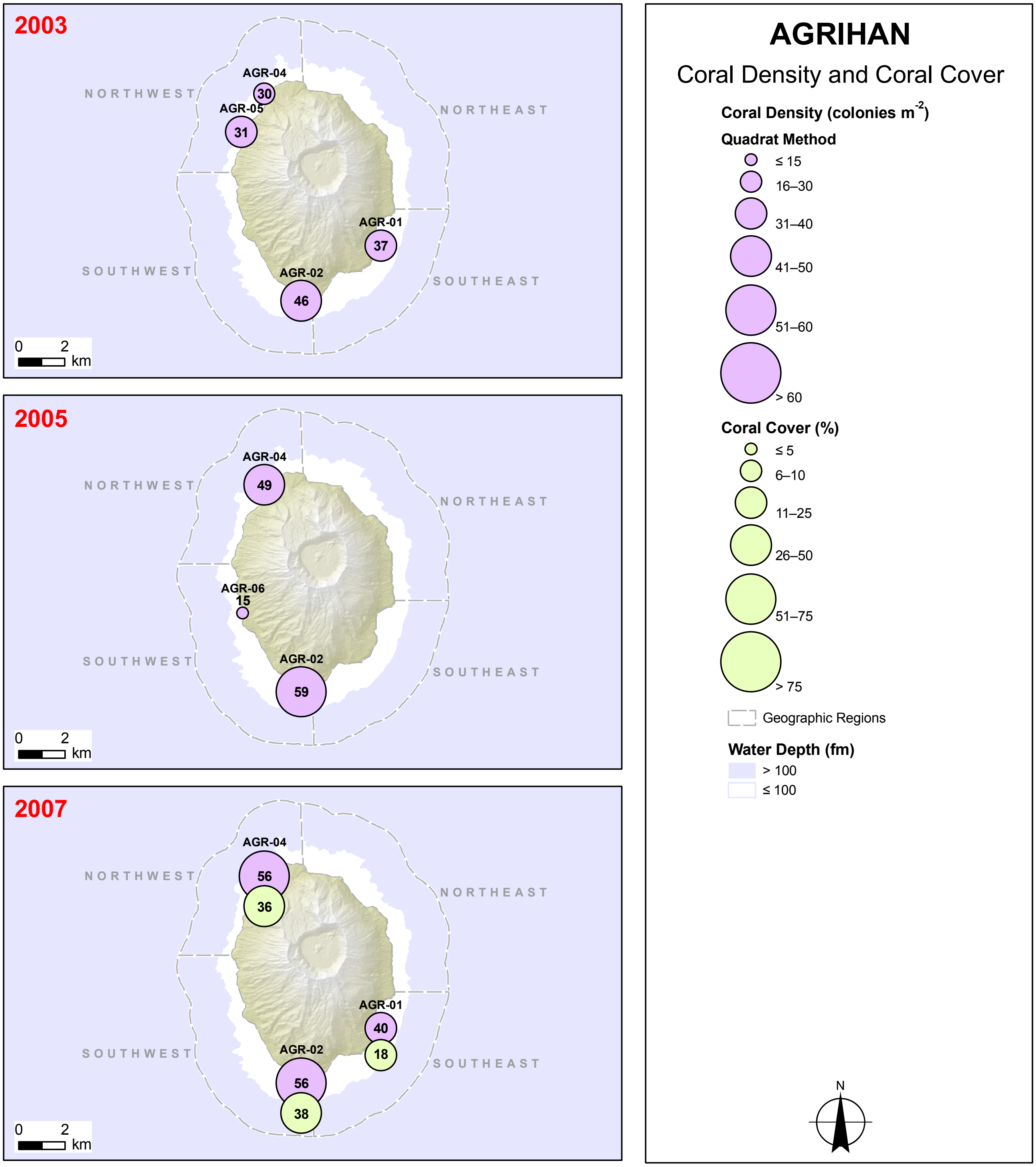


Figure 14.5.1b. Colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Agrihan during MARAMP 2003, 2005, and 2007 and cover (%) observations of live corals from REA benthic surveys during MARAMP 2007. Values are provided within or above each symbol. The quadrat method was used to assess coral-colony density.

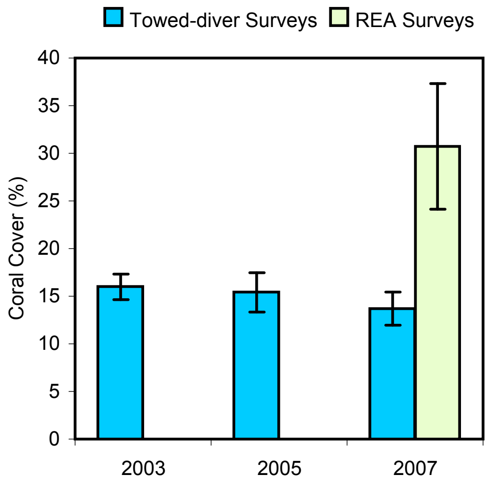


Figure 14.5.1c. Temporal comparison of mean live-coral-cover (%) values from REA and towed-diver surveys conducted on forereef habitats at Agrihan during MARAMP 2003, 2005, and 2007. No REA coral-cover surveys using the line-point-intercept method were conducted around Agrihan in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

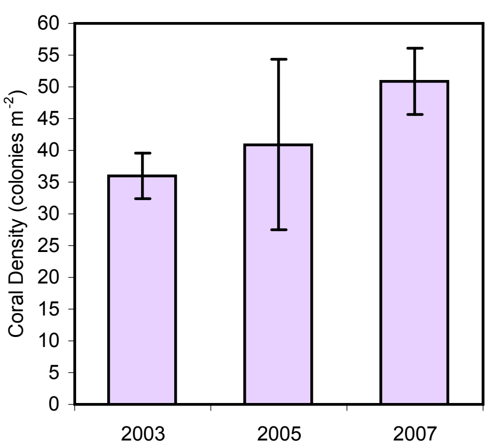


Figure 14.5.1d. Temporal comparison of mean coral-colony densities (colonies m^{-2}) from REA benthic surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. The quadrat method was used in the 3 MARAMP survey years to survey coral density. Error bars indicate standard error (± 1 SE) of the mean.

Islandwide mean cover of live corals estimated from towed-diver surveys of forereef habitats was 16% (SE 1.2) in 2003, 15% (SE 2.1) in 2005, and 14% (SE 1.7) in 2007 (Fig. 14.5.1c). Although there was substantial spatial variation between the 3 MARAMP survey years, the overall percentage of live coral cover was similar between survey years. For the 3 sites surveyed using the line-point-intercept method in 2007, the overall sample mean of live coral cover was 30.7% (SE 1.7). Estimates of live coral cover from REA surveys generally exceed those derived from towed-diver surveys because REA surveys target hard-bottom communities whereas towed-diver surveys include more variable substrate types.

The quadrat method was used during each of the 3 MARAMP survey years to assess coral-colony density. Overall mean coral-colony density from REA surveys of forereef habitats at Agrihan was 36 colonies m^{-2} (SE 3.6) in 2003, 40.9 colonies m^{-2} (SE 13.4) in 2005, and 51 colonies m^{-2} (SE 5.3) in 2007 (Fig. 14.5.1d). A similar temporal pattern exists when only the 2 sites surveyed in all of the 3 survey years (AGR-02 and AGR-04) are examined: mean density was 37.9 colonies m^{-2} (SE 8) in 2003, 54 colonies m^{-2} (SE 5.3) in 2005, and 56.3 colonies m^{-2} (SE 0.3) in 2007.

Coral Generic Richness and Relative Abundance

Four REA benthic surveys of forereef habitats were conducted using the quadrat method at Agrihan during MARAMP 2003. At least 22 coral genera were observed. Generic richness ranged from 13 to 17 with a mean of 15.5 (SE 0.8) coral genera per site (Fig. 14.5.1e, top panel). The highest generic diversity values were seen at AGR-05 and AGR-04 in the northwest region, and the lowest generic diversity was recorded at AGR-02 in the southern part of the southwest region. *Pavona*, *Goniastrea*, and *Favia* were the most numerically abundant genera, contributing 30.5%, 14.8%, and 12.1% of the total number of colonies enumerated at Agrihan in 2003. All other genera individually contributed < 10% of the total number of colonies. *Pavona* dominated the coral fauna at all 4 sites, contributing 26.8%, 32%, 30.4%, and 33.1% of the total number of colonies enumerated.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Agrihan during MARAMP 2005. At least 21 coral genera were observed. Generic richness ranged from 8 to 19 with a mean of 15 (SE 3.5) coral genera per site (Fig. 14.5.1e, middle panel). The highest generic diversity was seen at AGR-04 in the northwest region, and the lowest generic diversity was recorded at AGR-06 in the southwest region. *Pavona, Pocillopora, Goniastrea*, and *Leptastrea* were the most numerically abundant genera, contributing 16.2%, 13.9%, 13.7%, and 11.9% of the total number of colonies enumerated at Agrihanin 2005. All other genera individually contributed < 10% of the total number of colonies. *Leptastrea* dominated at AGR-06, accounting for 28.8% of the total number of colonies enumerated at that site. *Pocillopora* and *Porites* were each found to contribute 23.7% of the total number of colonies at AGR-06. *Goniastrea* dominated the coral fauna at AGR-02 and *Pavona* at AGR-04, contributing 23.2% and 21.5% of the total number of colonies recorded at their relevant site.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Agrihan during MARAMP 2007. At least 25 coral genera were observed. Generic richness ranged from 17 to 21 with a mean of 18.7 (SE 1.2) genera per site (Fig. 14.5.1e, bottom panel). The highest generic diversity was seen at AGR-01 in the southeast region, and the lowest generic diversity was recorded at AGR-04 in the northwest region. *Pavona*, *Pocillopora*, and *Goniastrea* were the most numerically abundant genera, contributing 23.9%, 15.0%, and 12.9% of the total number of colonies enumerated at

Agrihan in 2007. All other genera individually contributed < 10% of the total number of colonies. *Pavona* dominated the coral fauna at AGR-04 and AGR-02, contributing 32.3% and 27.7% of the total number of colonies recorded at those sites. *Astreopora* dominated at AGR-01, contributing 17.3% of the total number of colonies enumerated at that site.

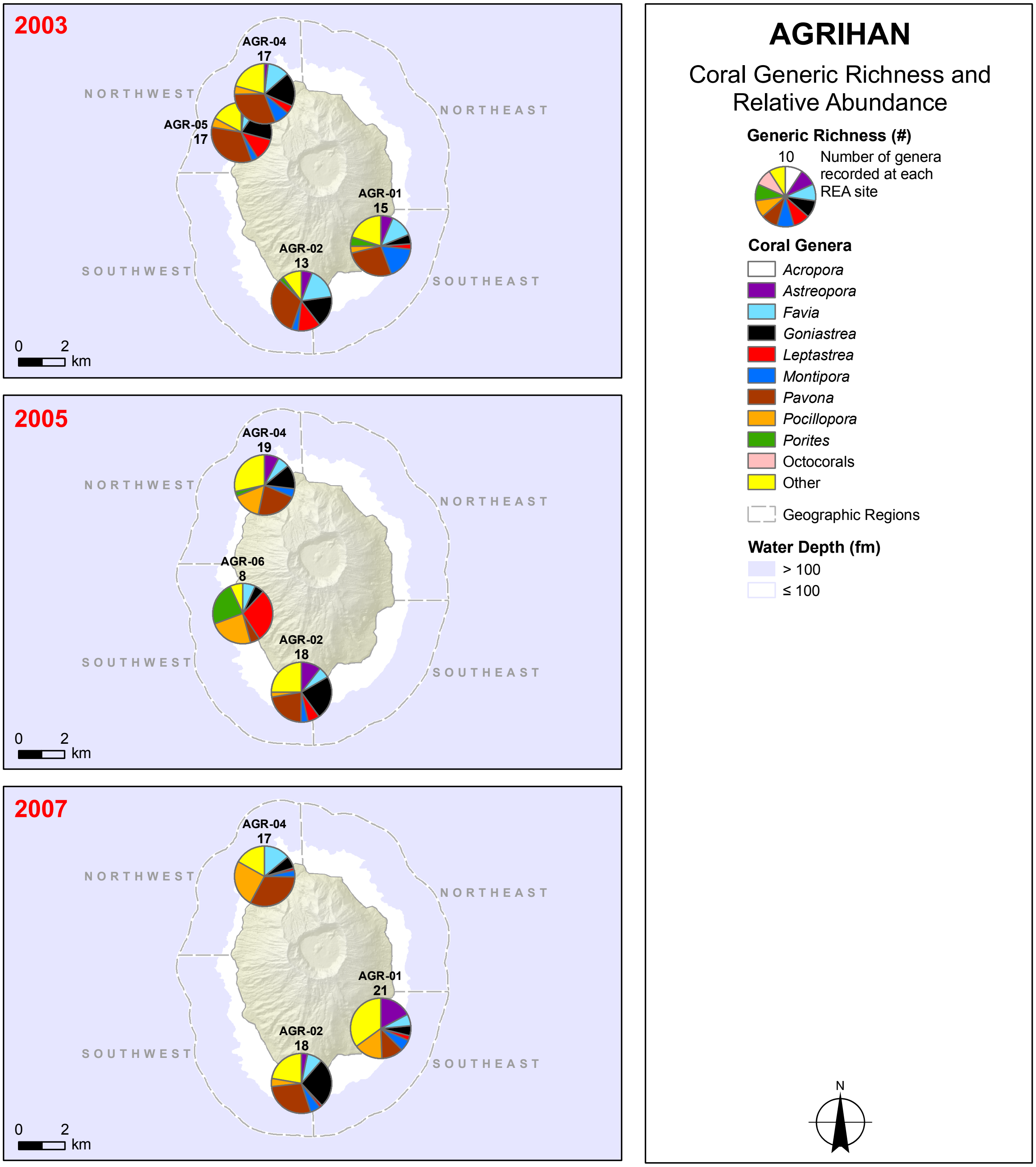


Figure 14.5.1e. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Agrihan during MARAMP 2003, 2005, and 2007. The pie charts indicate percentages of relative abundance of key coral genera.

The quadrat method was used in each of the 3 MARAMP survey years to assess generic richness on forereef habitats at Agrihan. Estimates for the overall sample mean of generic richness remained similar between MARAMP survey years, with 15.5 (SE 0.8) and 15 (SE 3.5) coral genera per site in 2003 and 2005 and 18.7 (SE 1.2) genera per site in 2007 (Fig. 14.5.1f). A different temporal pattern exists when only the 2 sites surveyed in all of the 3 survey years are examined (AGR-02 and AGR-04): mean generic richness increased from 15 (SE 2) genera per site in 2003 to 18.5 (SE 0.5) and 17.5 (SE 0.5) genera per site in 2005 and 2007. The increase in generic richness between 2003 and 2005 is not a result of new or additional genera being recorded at Agrihan in 2005, but to a greater number of genera being recorded at individual sites.

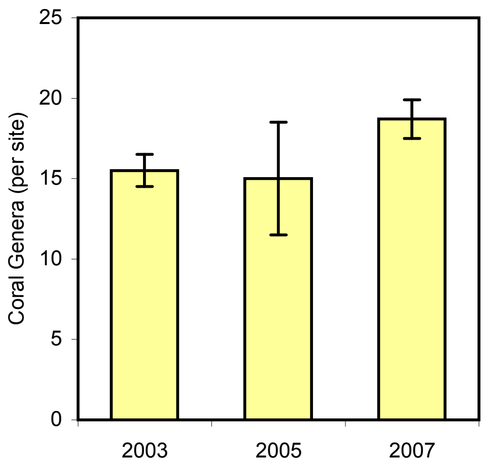


Figure 14.5.1f. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Agrihan during MARAMP 2003, 2005, and 2007. The quadrat method was used in the 3 MARAMP survey years to survey coral genera. Error bars indicate standard error (± 1 SE) of the mean.

Across the 3 MARAMP survey years, 28 coral genera were observed on forereef habitats at Agrihan. *Pavona* and *Goniastrea* were important components of the coral fauna, accounting for > 10% of the total number of colonies enumerated in the 3 survey years. *Pavona* was the most numerically abundant taxon in each of the 3 survey years, contributing 30.5%, 16.2%, and 23.9% to the total number of colonies. *Goniastrea* was the second-most numerically abundant taxon in 2003, accounting for 14.8% of the colonies recorded that year, while *Pocillopora* was the second-most numerically abundant taxon in 2005 and 2007, contributing 13.9% and 15%, of the total number of colonies enumerated in those years. *Favia* was the third-most numerically abundant taxon in 2003, contributing 12.1% of the colonies, while *Goniastrea* was the third-most abundant taxon represented in 2005 and 2007, contributing 13.7% and 12.9% of the total number of colonies. All other taxa contributed < 12% of the total number of colonies enumerated over the 3 survey years.

Coral Size-class Distribution

During MARAMP 2003, 4 REA benthic surveys of forereef habitats were conducted at Agrihan using the quadrat method. The coral size-class distributions from these surveys show that the majority (61.5%) of corals had maximum diameters ≤ 5 cm (Fig. 14.5.1g, top panel). The next 4 size classes (6–10, 11–20, 21–40 and 41–80 cm) accounted for 30.1%, 7.1%, 3.8%, and 0.6% of colonies recorded. No colonies with maximum diameters > 80 cm were recorded. At all REA sites, a majority of all measured corals (> 64%) were in the smallest size class (0–5 cm), except for at AGR-04, where 49% of corals had maximum diameters ≤ 5 cm.

During MARAMP 2005, 3 REA benthic surveys of forereef habitats were conducted at Agrihan using the quadrat method. The coral size-class distributions from these surveys show that the majority (77.9%) of corals had maximum diameters ≤ 5 cm (Fig. 14.5.1g, middle panel). The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 14.4%, 7.9%, 2.8%, and 0.7% of colonies recorded. No colonies with maximum diameters > 80 cm were recorded. At all REA sites, a majority (> 66%) of corals were in the smallest size class (0–5 cm).

During MARAMP 2007, 3 REA benthic surveys of forereef habitats were conducted at Agrihan using the quadrat method. The coral size-class distributions from these surveys show that the majority (64.3%) of corals had maximum diameters ≤ 5 cm (Fig. 14.5.1g, bottom panel). The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 24.9%, 8.1%, 2.1%, and 1.3% of colonies recorded. Colonies with maximum diameters > 80 cm contributed 0.5% of colonies recorded. At all REA sites, a majority (> 69%) of corals was in the smallest size class (0–5 cm), except for at AGR-02, where 49.1% of corals had maximum diameters ≤ 5 cm.

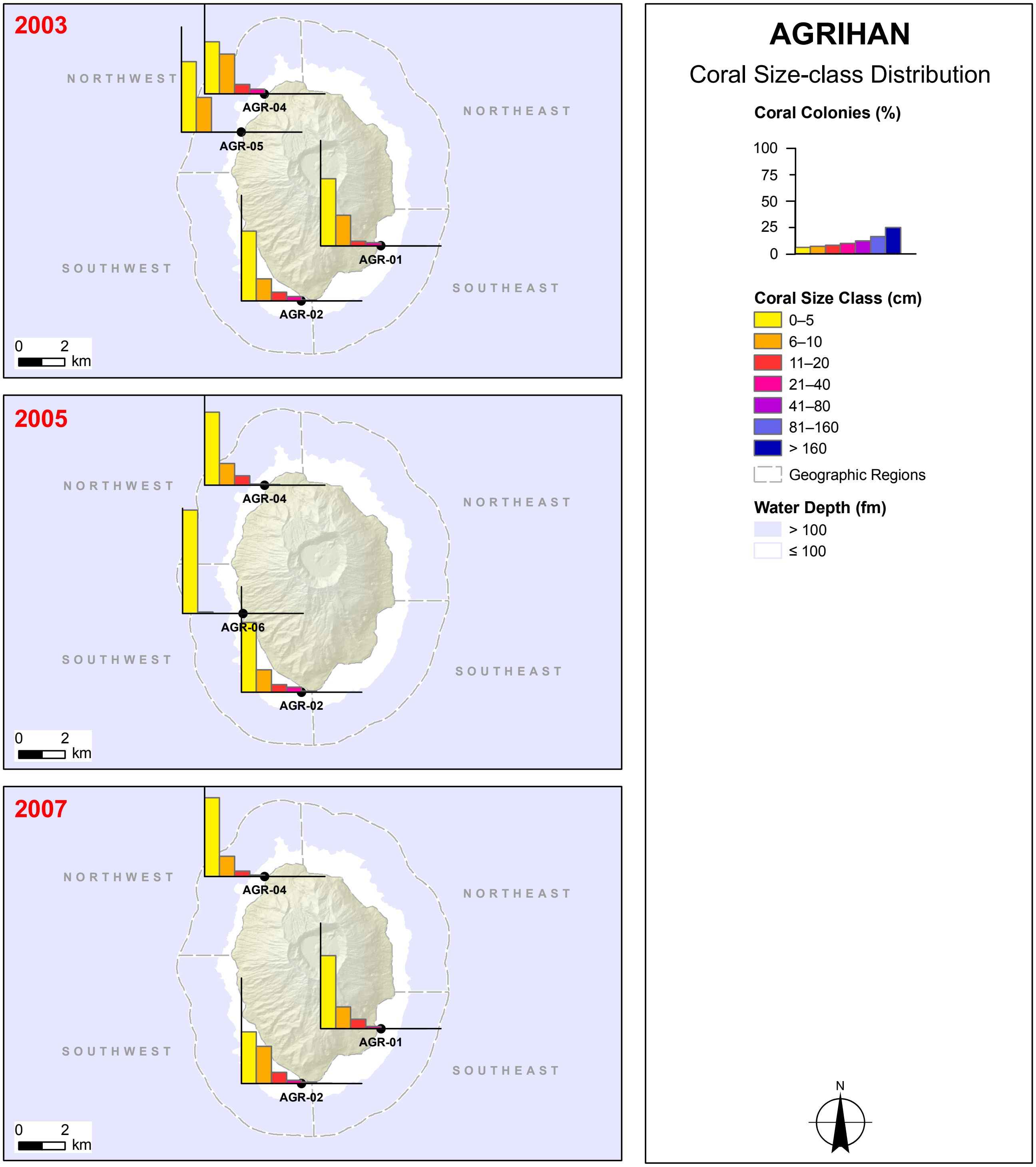
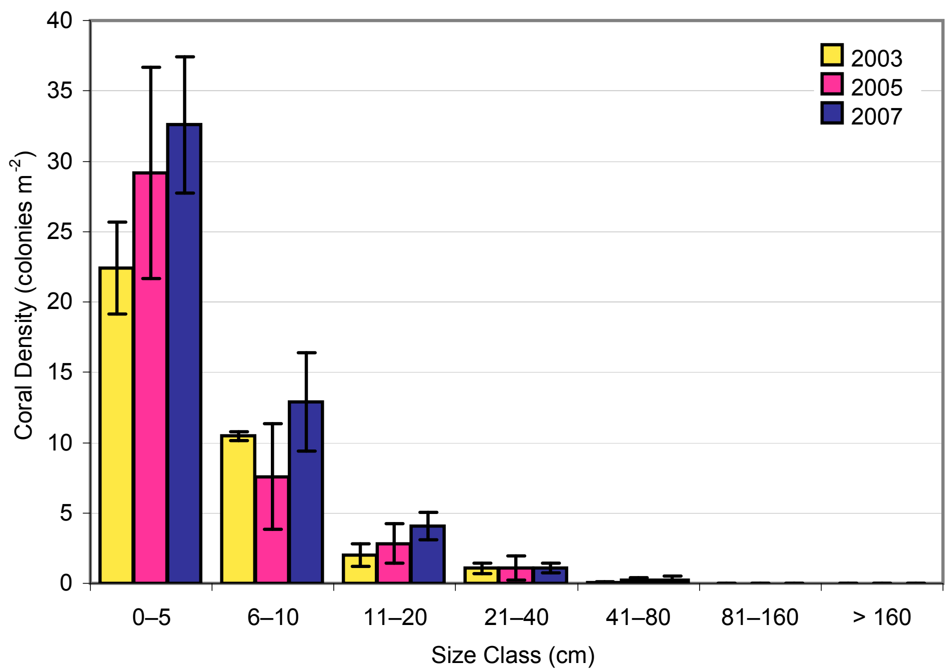


Figure 14.5.1g. Size-class distributions of hard corals from REA benthic surveys conducted on forereef habitats at Agrihan during MARAMP 2003, 2005, and 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used to size corals.

The quadrat method was used to establish size-class distributions on forereef habitats at Agrihan during the 3 MARAMP survey periods. Corals whose center fell within the borders of a quadrat (50 × 50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes. At each site, 15 or 16 such quadrats were examined (total survey area = 3.75 or 4 m^2), enabling observers to closely inspect and record each coral colony within the quadrat. For more on these survey methods, see Chapter 2, "Methods and Operational Background, Section 2.4.5: "Corals and Coral Disease."

In each of the 3 MARAMP survey years, the number of colonies in the smallest size class (0–5 cm) was much higher than the number of colonies in the larger size classes (Fig. 14.5.1h). The overall mean proportion of colonies censused on forereef habitats at Agrihan that fell in the smallest size class (0–5 cm) increased from 61.5% in 2003 to 77.9% in 2005 but decreased to 64.3% in 2007. Values for individual sites surveyed in all of the 3 survey years (AGR-02 and AGR-04) were variable between years with mean proportion of colonies with maximum diameters ≤ 5 cm at AGR-02 decreasing between years but increasing at AGR-04. Concordantly, the overall mean proportion of colonies in all other size classes was variable between years, as were all site-specific proportions. The higher frequency of the smallest size class may result from recruitment, fragmentation of existing colonies, or both. Minor variation between overall and site-specific size-class distributions recorded in 2003, 2005 and 2007 likely result from chance differences in the placement of individual quadrats.

Figure 14.5.1h. Mean coral-colony densities (colonies m^{-2}) by size class from REA benthic surveys of forereef habitats conducted at Agrihan during MARAMP 2003, 2005, and 2007. The quadrat method was used in each of the 3 survey years to size corals. Error bars indicate standard error (± 1 SE) of the mean.



14.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic disease surveys for coral disease and predation were conducted at 3 sites on forereef habitats at Agrihan, covering a total area of 900 m^2. Surveys detected 5 cases of disease, translating to an overall mean prevalence of 0.01% (SE 0.01). The use of the quadrat method for coral-colony counts at all REA sites at Agrihan resulted in higher-than-expected coral-colony densities, and, therefore, lower-than-expected disease prevalence values.

Three disease conditions were observed at Agrihan. In order of numerical abundance, these conditions were fungal infection, skeletal growth anomalies, and bleaching. All 3 of the sites surveyed contained disease, however, in low prevalence values (Fig. 14.5.2a and b). Disease conditions involving skeletal growth anomalies were observed at AGR-01 and AGRI-04 on corals of the genera *Acropora*, *Goniastrea*, and *Astreopora*. Cases of fungal infections were observed at AGR-02 and AGR-04 on corals of the genera *Astreopora* and *Coscinaraea*. Bleaching conditions were recorded only at AGR-02 on corals of the genus *Platygyra*. Only one case of COTS predation was enumerated at Agrihan; this case was detected at AGU-04 on a colony of the genus *Goniastrea*. For more information about COTS at Agrihan, see Section 14.7.1: "Benthic Macroinvertebrate Surveys."

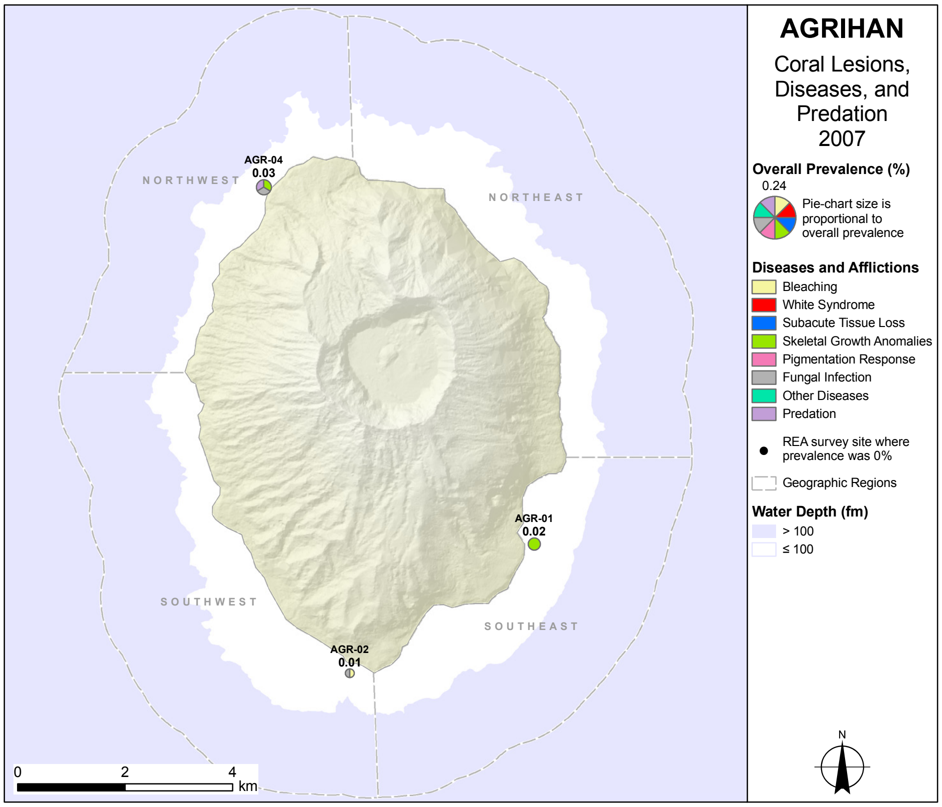


Figure 14.5.2a. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted at Agrihan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The color-coded portions of the pie chart indicate disease-specific prevalence.

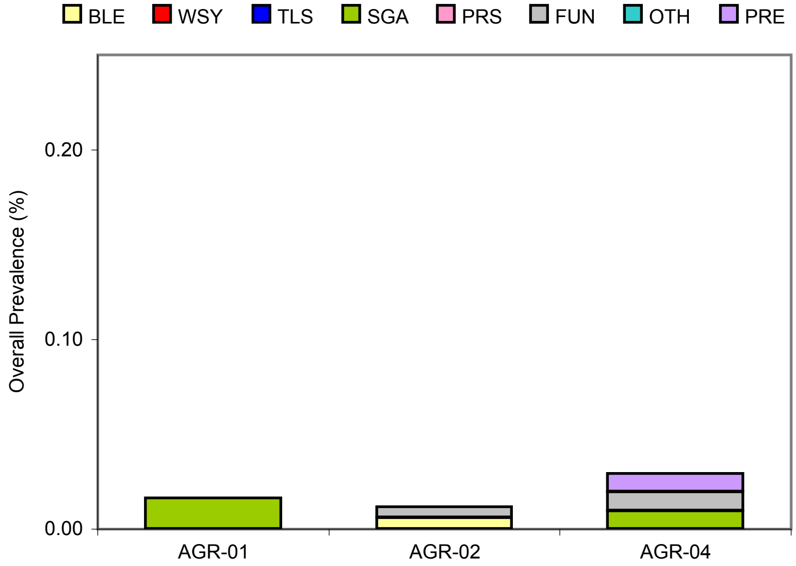


Figure 14.5.2b. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted at Agrihan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The order of conditions presented in the bars is the same as the order in the legend. BLE: bleaching; WSY: white syndrome; TLS: subacute tissue loss; SGA: skeletal growth anomalies; PRS: pigmentation response; FUN: fungal infection; OTH: algal and cyanophyte infections and other lesion of unknown etiology; PRE: predation by COTS or corallivorous snails.

14.6 Algae and Algal Disease

14.6.1 Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats around the island of Agrihan was 48% (SE 2.2). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 74% occurred along the central part of the west coast in the northwest and southwest regions (Fig. 14.6.1a, top left panel). The habitat in this area had pavement, bedrock, and rubble of medium to medium-high complexity. Other surveys in the southwest and northwest regions also showed high macroalgal cover with means of 66% and 64%. In the southern half of the southwest region, the towed-diver survey with the lowest mean macroalgal cover of 1.7% occurred in the vicinity of Agrihan Anchorage (for place-names and their locations, see Figure 14.2a in Section 14.2: "Survey Effort").

TOAD surveys completed at Agrihan during MARAMP 2003 were conducted at depths of 20–165 m. Analyses of TOAD video footage obtained from 8 surveys suggested that there was almost no macroalgae, at least as seen in a majority of images (Fig. 14.6.1a, top left panel). Macroalgae were present in only a single video frame.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats at Agrihan was 23% (SE 2.8). The survey with the highest mean macroalgal cover of 37% occurred in the northernmost part of the northwest region (Fig. 14.6.1a, middle left panel). Habitat complexity was medium to medium-high in this area. The second-greatest mean macroalgal cover of 33% was found during a survey completed in the northeast region. The survey with the lowest mean macroalgal cover of 2.2% occurred around the southern point of Agrihan over habitat with high complexity.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats at Agrihan was 9% (SE 1.4%). The survey with the highest mean macroalgal cover of 21% occurred in the northeast region (Fig. 14.6.1a, bottom left panel), over medium-complexity habitat that included rock ridges with boulders in between, boulders on sand, and a gentle slope. The lowest macroalgal-cover values, with means of 3.4%–6.6%, were recorded during 3 surveys conducted in the southwest region.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats around Agrihan were conducted using the line-point-intercept method. No macroalgae were observed at any of the REA sites surveyed. Turf-algal cover ranged from 35.3% to 53.9% with an overall mean of 46% (SE 5.5). The highest turf-algal cover was recorded in the southeast region at REA site AGR-01. Relatively high (48%) turf-algal cover also was found at AGR-04 in the northwest region. AGR-02 in the southwest regions had the lowest turf-algal cover (Fig. 14.6.1b).

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Agrihan was 9% (SE 0.6). The survey with the highest mean crustose-coralline-red algal cover of 19% occurred in the southwest region (Fig 14.6.1a, top right panel). The lowest cover values of crustose coralline red algae with means of 0%–3% were recorded during 3 surveys: near Agrihan Anchorage in the southwest region, at the southern tip of this island, and in the northern part of the southeast region.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Agrihan was 6% (SE 0.8). The survey with the highest mean crustose-coralline-red-algal cover of 9% occurred in the northernmost part of the northwest region (Fig. 14.6.1a, middle right panel). The lowest mean crustose-coralline-red algal cover of 2.3% was recorded during surveys in the northeast region and around the southern tip of this island.

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae around Agrihan was 10% (SE 1). The survey with the highest mean crustose-coralline-red algal cover of 20% occurred in the northernmost part of the northwest region (Fig. 14.6.1a, bottom right panel). The dominant habitat in this area was of continuous reef and ridges of medium to very high complexity. In comparison with this survey, all other towed-diver surveys conducted at Agrihan in 2005 recorded low levels (≤ 7.5%) of mean crustose-coralline-red-algal cover. The lowest mean crustose-coralline-red algal cover of 3.5% was recorded during a survey in the northwest region.

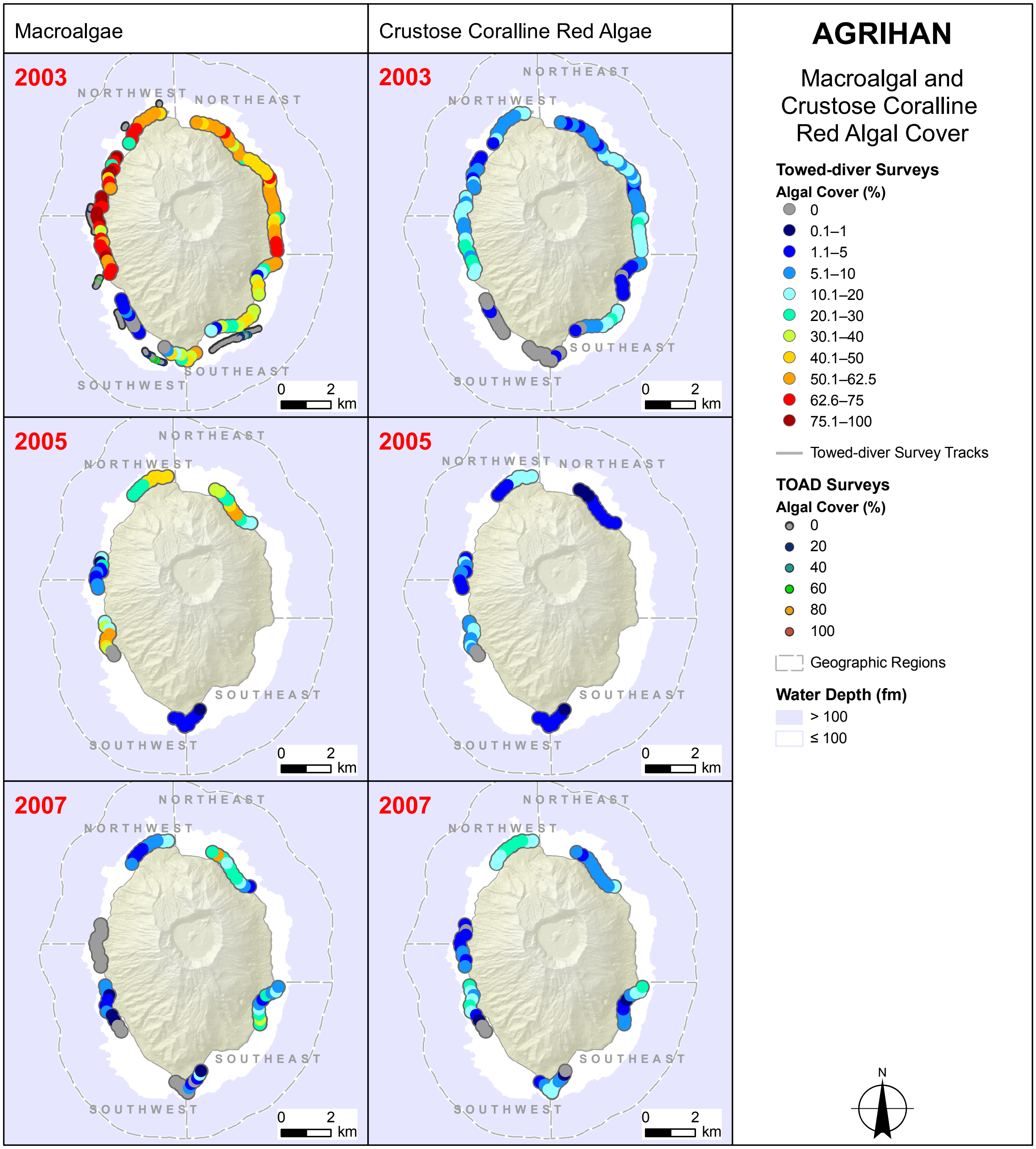
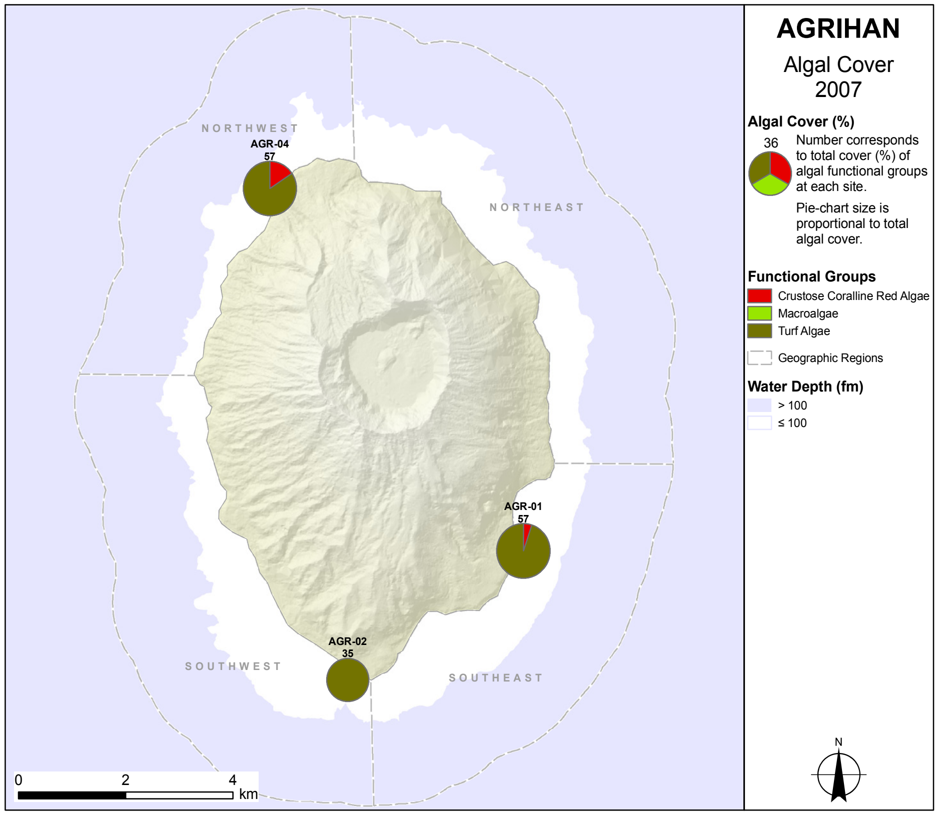


Figure 14.6.1a. Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003). In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats around Agrihan were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red-algal cover ranged from 0% to 8.8% with an overall mean of 4% (SE 2.6). The survey with the highest cover of crustose coralline red algae occurred in the northwest region at AGR-04 (Fig. 14.6.1b). No crustose coralline red algae were recorded at AGR-02 in the southwest region.

Figure 14.6.1b. Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method at Agrihan during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.



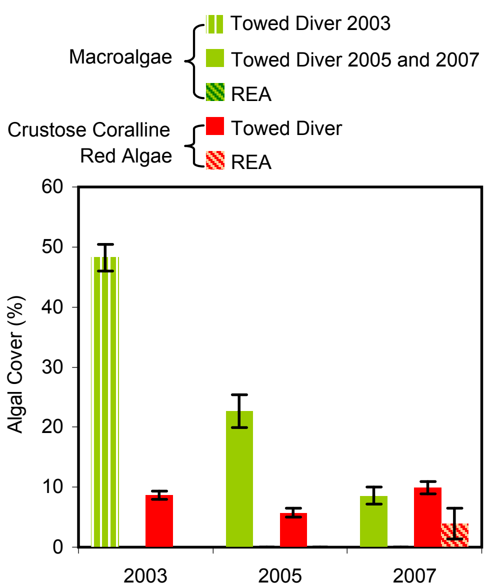


Figure 14.6.1c. Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003. No REA algal-cover surveys using the line-point-intercept method were conducted at Agrihan in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations around Agrihan, based on towed-diver surveys, decreased considerably from 23% (SE 2.8) in 2005 to 9% (SE 1.4) in 2007 (Fig. 14.6.1c). When considering survey results, keep in mind that turf algae was included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Also, fewer surveys were conducted around Agrihan in 2005 and 2007 (when surveys were limited to one day) than in 2003. Other factors could have contributed to differences in estimates of algal cover (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Crustose-coralline-red-algal populations around Agrihan, based on towed-diver surveys of forereef habitats, varied slightly between MARAMP survey years and was ≤ 10% for each of the 3 MARAMP survey years. In 2003, the highest cover of crustose coralline red algae was recorded during a towed-diver survey completed in the southwest region, but, in 2005 and 2007, the highest cover was found during the northernmost survey in the northwest region. Since many surveys documented cover values ≤ 5%, no consistent spatial trend was observed between years for the lowest values of crustose-coralline-red-algal cover.

Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites is about 90% complete for the northern islands of the Mariana Archipelago with hundreds of species identified so far. Ultimately, based on this microscopic analysis, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 6 sites on forereef habitats at Agrihan. In the field, 18 macroalgal genera (6 red, 8 green, and 4 brown), containing at least 18 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. AGR-05 in the northwest region had the highest macroalgal generic diversity with 11 genera, containing 11 species, documented in the field. The lowest macroalgal generic diversities were found at AGR-02 and AGR-06 in the southwest region with 2 species representing 2 genera recorded.

Species of the green algal genus *Neomeris* were common at Agrihan in 2003, occurring in 25% of sampled photoquadrats and at 5 of the 6 sites surveyed (Fig. 14.6.1d, top panel). The highest occurrence of the genus *Neomeris* was found in the northwest region at AGR-04, where it was observed in 50% of sampled photoquadrats. The green alga *Caulerpella ambigua* and species of the calcified green algal genus *Halimeda* were common members of the algal community at AGR-01 in the southeast region. Although the brown algal genus *Lobophora* had the highest overall occurrence (27.8%) of any algal genus seen in the sampled photoquadrats, it was recorded only at AGR-05 and AGR-06 in the northwest and southwest regions, occurring in 83.3% of photoquadrats sampled at each site. Of the remaining 14 taxa tentatively identified, only species of the red algal genus *Amphiroa* were observed at more than 2 sites, making distinctive spatial patterns of distribution difficult to determine for most macroalgae at Agrihan.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2003, occurring in 86.1%, 44.4%, and 23.6% of photoquadrats sampled at Agrihan (Fig. 14.6.1d, top panel). Turf algae were ubiquitous across all sites, while crustose coralline red algae and cyanbacteria were missing only from a single site in the southwest region, AGR-03 or AGR-02, respectively. Both crustose coralline red algae and cyanobacteria had higher occurrence values in the northwest region than in other regions.

During MARAMP 2005, REA benthic surveys were conducted at 3 sites on forereef habitats at Agrihan. In the field, 9 macroalgal genera (2 red, 4 green, and 3 brown), containing at least 9 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, nongeniculate calcified red algae, and cyanophytes—were observed. AGR-06 in the southwest region had the highest macroalgal generic diversity with 7 genera, containing 7 species, documented in the field. The lowest macroalgal generic diversity was found at AGR-02, located farther south in the southwest region, with 6 species representing 6 genera recorded.

Species of the brown macroalgal genera *Lobophora* and *Dictyota* and the red algal genus *Jania* were all ubiquitous at every site surveyed at Agrihan in 2005, occurring in 80.6%, 16.7%, and 63.9% of sampled photoquadrats (Fig. 14.6.1d, middle panel). Species of the green algal genus *Dictyosphaeria,* although found at only 1 site, was observed in 41.7% of photoquadrats sampled at AGR-06. Of the 9 macroalgal species tentatively identified in the field, only a select few showed any pattern of spatial distribution. Species of *Lobophora* were most prevalent in the northwest region, and the lowest occurrence (41.7%) of this genus was found at AGR-02 in the southwest region. Species of *Jania* were less common at AGR-02 than at AGR-04 in the northwest region, occurring in 16.7%–100% of sampled photoquadrats at these 2 sites.

Turf algae and crustose coralline red algae were both abundant in 2005, occurring in 91.7% and 55.6% of photoquadrats sampled at Agrihan (Fig. 14.6.1d, middle panel). Cyanobacteria, found at 2 of the 3 sites surveyed, were a minor component of the algal community at Agrihan, occurring in 8.3%–25% of photoquadrats sampled at AGR-06 in the southwest region and AGR-04 in the northwest region. Nongeniculate, calcified, branched red algae, also a minor component of this algal community, were recorded in 8.3% of photoquadrats sampled at only 1 site, AGR-04.

During MARAMP 2007, REA benthic surveys were conducted at 3 sites on forereef habitats at Agrihan. In the field, 19 macroalgal genera (9 red, 6 green, and 4 brown), containing at least 19 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. AGR-01 in the southeast region had

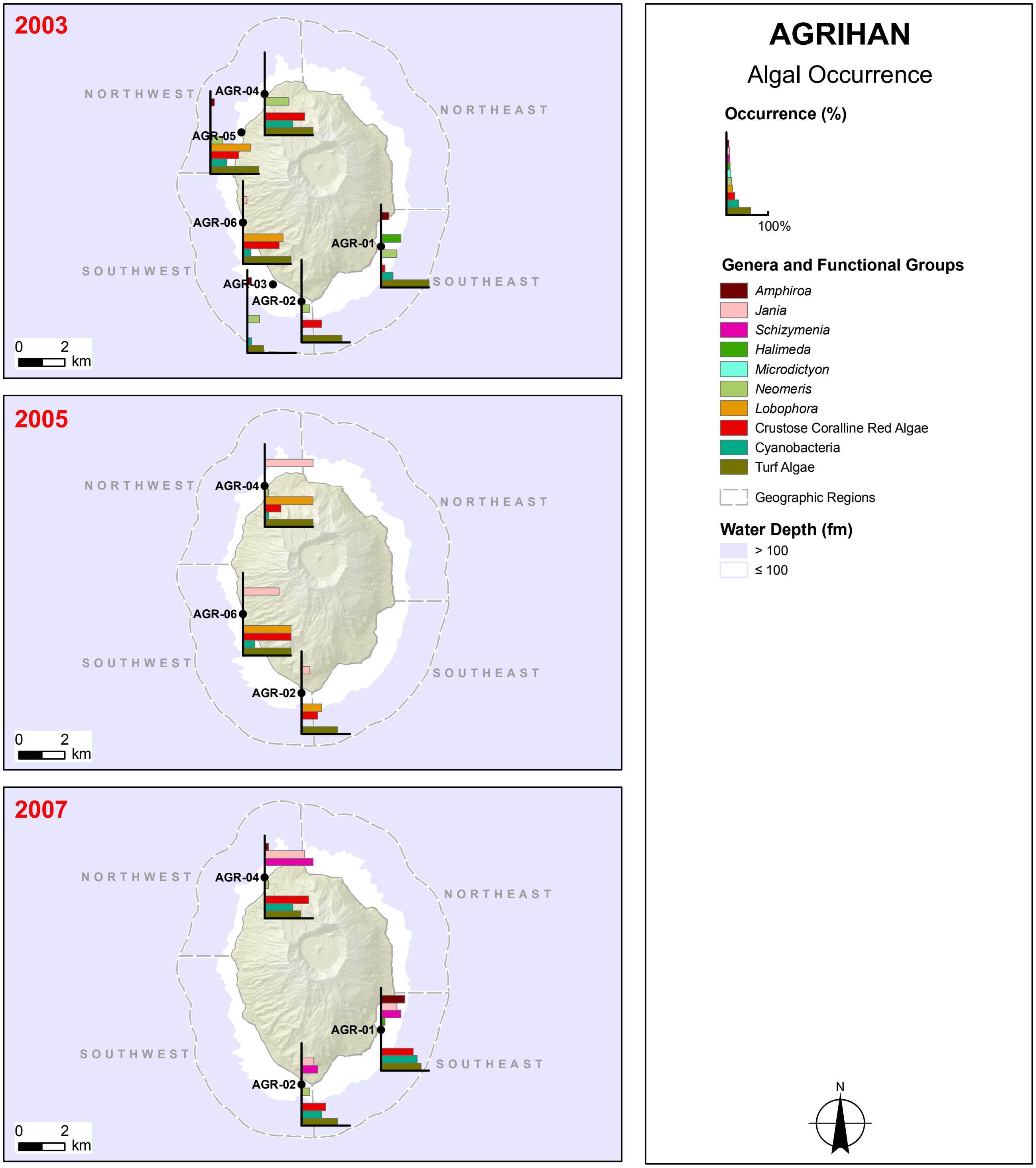


Figure 14.6.1d. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted at Agrihan during MARAMP 2003, 2005, and 2007. Occurrence is equivalent to the percentage of photo-quadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

the highest macroalgal generic diversity with 15 genera, containing 15 species, documented in the field. The lowest macroalgal generic diversity was found near the southern tip of this island at AGR-02 in the southwest region with 6 species representing 6 genera recorded.

Species of the red macroalgal genera *Schizymenia* and *Jania* were ubiquitous at every site surveyed at Agrihan in 2007, occurring in 58.3% and 47.2% of sampled photoquadrats (Fig. 14.6.1d, bottom panel). Species of *Dictyota* also were ubiquitous at every site surveyed, occurring in 16.7%–33.3% of sampled photoquadrats at Agrihan. Of the 19 macroalgal genera tentatively identified in the field, 12 were found only at 1 site, making distinctive spatial patterns of distribution difficult to determine for most macroalgae at Agrihan. However, species of *Schizymenia* were observed in more sampled photoquadrats AGR-04 (100%) in the northwest region than at AGR-02 (33.3%) in the southwest region. Species of *Jania* were seen in a similar pattern of distribution, occurring in 83.3% and 25% of sampled photoquadrats at AGR-04 and AGR-02.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2007, occurring in 77.8%, 69.4%, and 58.3% of photoquadrats sampled at Agrihan (Fig. 14.6.1d, bottom panel). Crustose coralline red algae were more prevalent in the northwest region at AGR-04 than in the southwest region at AGR-02, where they were found in 91.7% and 50% of photoquadrats sampled at those sites. No other patterns of spatial distribution were apparent for these functional groups.

The number of macroalgal genera recorded on forereef habitats at Agrihan decreased from 18 to 9 between MARAMP 2003 and 2005 but increased to 19 during MARAMP 2007. Differences in survey effort and other factors likely can account for small changes in estimated macroalgal diversity (for information on data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”). Overall patterns of distribution for common macroalgal genera did not fluctuate dramatically between MARAMP survey years. Species of *Dictyota* were consistently prominent members of the macroalgal community during the 3 survey years, with mean occurrence of 4.2%–22.2% and a slight increasing change in abundance (Fig. 14.6.1d). Species of *Lobophora* also were abundant members of the macroalgal community with occurrence values of 27.7% in 2003 and 80.6% in 2005; however, no members of this genus were documented in 2007. Species of *Jania* showed an increase in occurrence from 1.4% in 2003 to 63.9% in 2005 but a decrease in occurrence to 47.2% in 2007.

Across the 3 MARAMP survey years, crustose coralline red algae occurred in 44.4%–69.4% of photoquadrats sampled at Agrihan, with a slight increase in abundance each year (Fig. 14.6.1d). No temporal trends in abundance were observed on forereef habitats at Agrihan for turf algae or cyanobacteria, which occurred in 77.8%–91.7% and 11.1%–58.3% of sampled photoquadrats in the 3 survey years.

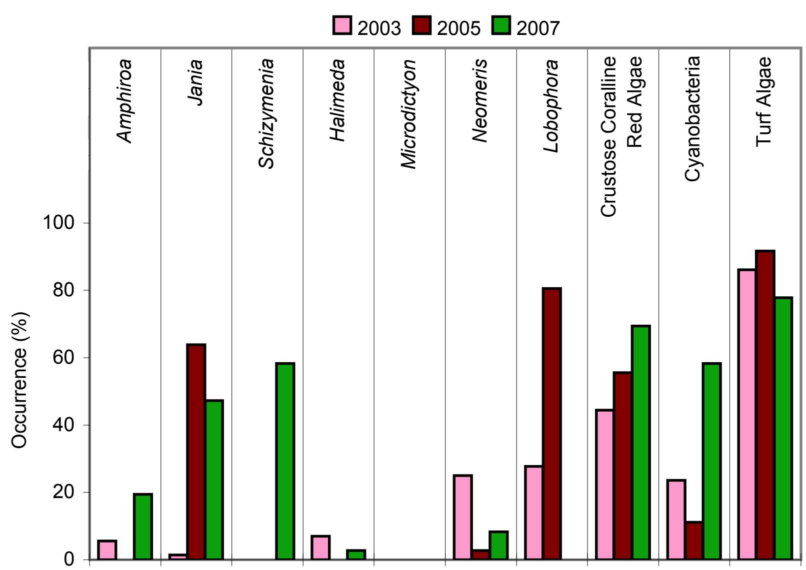


Figure 14.6.1f. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats at Agrihan during MARAMP 2003, 2005, and 2007.

14.6.2 Surveys for Coralline-algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral-disease assessments at 3 sites on forereef habitats at Agrihan. These surveys covered a total reef area of 900 m^2. No cases of coralline-algal disease were detected.

14.7 Benthic Macroinvertebrates

14.7.1 Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and crown-of-thorns seastars (COTS)—were monitored on forereef habitats around the island of Agrihan through REA and towed-diver benthic surveys during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during the REA invertebrate surveys is provided in Chapter 3: "Archipelagic Comparisons."

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 6 REA surveys and 12 towed-diver surveys were conducted around Agrihan. In 2005 and 2007, 3 REA surveys and 5 and 6 towed-diver surveys were performed at Agrihan. When considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Overall, both REA and towed-diver surveys suggested low daytime macroinvertebrate abundance on forereef habitats around Agrihan compared to other surveyed sites in the Mariana Archipelago. Minor fluctuations in observed densities between MARAMP survey periods occurred with all target groups. Temporal patterns of islandwide mean benthic macroinvertebrate density around Agrihan—from towed-diver benthic surveys during the MARAMP 2003, 2005, and 2007—are shown later in this section (Figs.14.7.1b, d, f, and h).

Giant Clams

During MARAMP 2003, species of *Tridacna* giant clams were observed at 2 of the 6 REA sites and in 9 of the 12 towed-diver surveys conducted around Agrihan (Fig. 14.7.1a, top panel). The overall mean density of giant clams from REA surveys was 0.83 organisms 100 m^{-2} (SE 0.65), and the islandwide mean density from towed-diver surveys was 0.03 organisms 100 m^{-2} (SE 0.01). Survey results suggest that giant clams were most abundant at REA site AGR-02 in the southwest region with 4 organisms 100 m^{-2}. Among all towed-diver surveys around Agrihan, a survey completed along the western shore had the highest mean density of giant clams with 0.14 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.67 organisms 100 m^{-2}. The second-greatest mean density of giant clams from a towed-diver survey was 0.06 organisms 100 m^{-2}, also recorded along the western shoreline; segment densities ranged from 0 to 0.14 organisms 100 m^{-2}.

During MARAMP 2005, giant clams were observed at 1 of the 3 REA sites surveyed and in all 5 towed-diver surveys conducted around Agrihan (Fig. 14.7.1a, middle panel). The density of giant clams at AGR-02 was 1 organism 100 m^{-2}. The overall mean density from towed-diver surveys was 0.04 organisms 100 m^{-2} (SE 0.01). Among all towed-diver surveys around Agrihan, the surveys completed along the western shore had the highest mean densities of giant clams with 0.05 and 0.08 organisms 100 m^{-2}; segment densities from both these surveys ranged from 0 to 0.34 organisms 100 m^{-2}.

During MARAMP 2007, giant clams were observed at all 3 REA sites surveyed and in all 6 towed-diver surveys conducted at Agrihan (Fig. 14.7.1a, bottom panel). The sample mean density of giant clams from REA surveys was 0.56 organisms 100 m^{-2} (SE 0.22), and the overall mean density from towed-diver surveys was 0.04 organisms 100 m^{-2} (SE 0.01). Survey results suggest that giant clams were most abundant at AGR-02 with 1 organism 100 m^{-2}. Among all towed-diver surveys around Agrihan, the surveys completed along the western coast had the highest mean densities of giant clams with 0.06 organisms 100 m^{-2} for both surveys; segment densities for these surveys ranged from 0 to 0.22 organisms 100 m^{-2}.

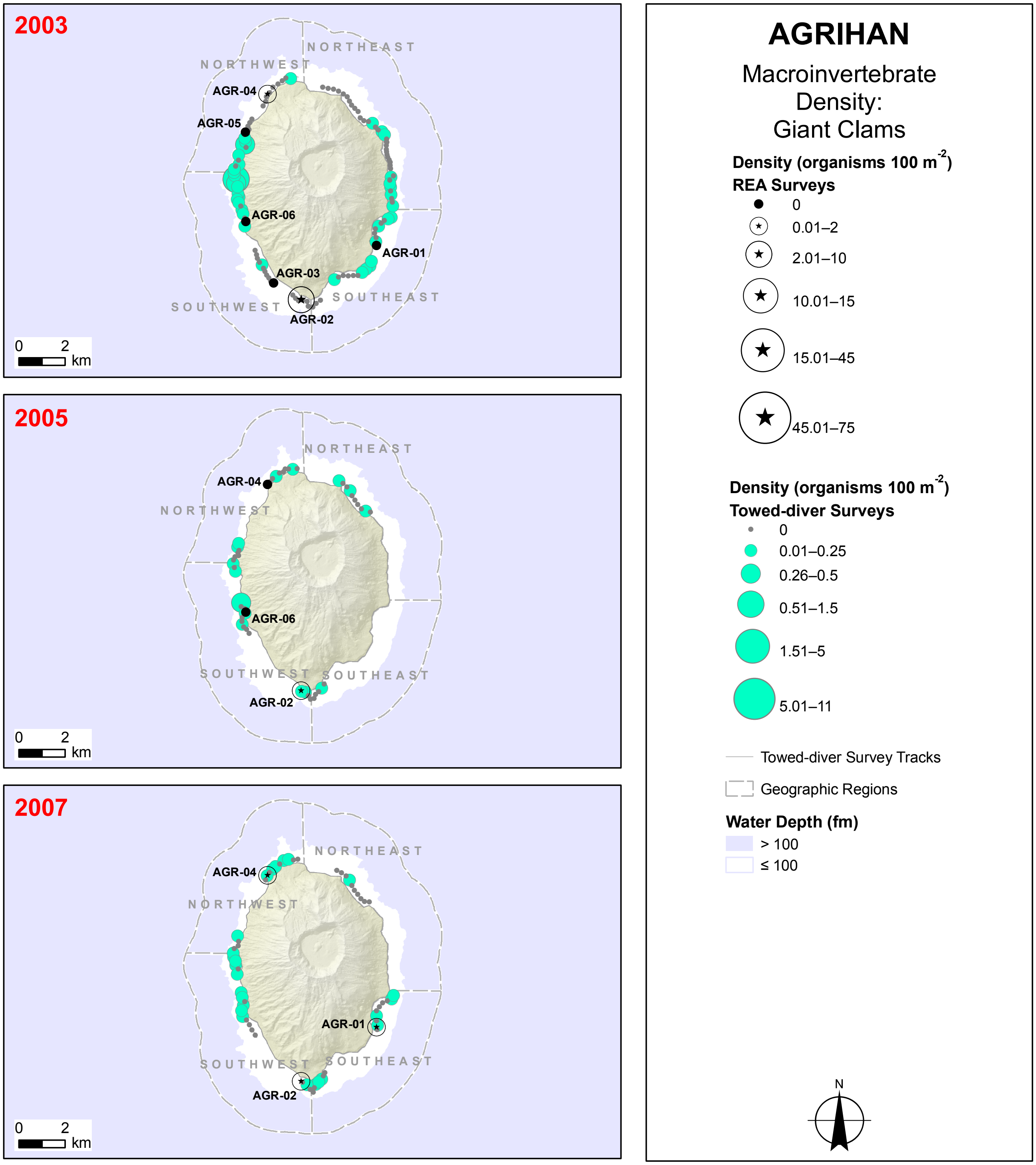


Figure 14.7.1a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Agrihan in 2003, 2005, and 2007.

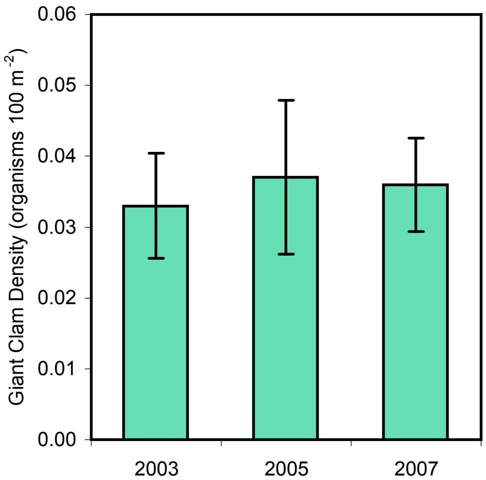


Figure 14.7.1b. Temporal comparison of mean densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested low abundance of giant clams around Agrihan during the 3 MARAMP survey periods, relative to the rest of the Mariana Archipelago. The overall observed mean density of giant clams around Agrihan was consistent between survey years (Fig. 14.7.1b), and giant clams were more abundant along the western shoreline than on the east side of this island. However, survey efforts were different between survey years, with fewer towed-diver surveys conducted along the east coast in 2005 and 2007 than in 2003 (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Crown-of-thorns Seastars

During MARAMP 2003, crown-of-thorns seastars (*Acanthaster planci*) were observed only at 1 of the 6 REA sites surveyed and in 1 of the 12 towed-diver surveys conducted around Agrihan (Fig. 14.7.1c, top panel). AGR-01 had a COTS density of 1 organism 100 m^{-2}. The towed-diver survey in the northeast region had a recording of COTS with a mean density of 0.004 organisms 100 m^{-2} (SE 0.517); segment densities from this survey ranged from 0 to 0.042 organisms 100 m^{-2}.

During MARAMP 2005, no COTS were observed at the 3 REA sites surveyed at Agrihan, but 2 of the 5 towed-diver surveys had recordings of COTS, with an overall mean density of 0.06 organisms 100 m^{-2} (SE 0.028). The towed-diver survey completed in the northeast region had the greatest mean density of COTS with 0.286 organisms 100 m^{-2} (Fig. 14.7.1c, middle panel); segment densities from this survey ranged from 0 to 0.966 organisms 100 m^{-2}. The towed-diver survey in the southwest region had a mean density of 0.016 organisms 100 m^{-2}; segment densities ranged from 0 to 0.068 organisms 100 m^{-2}.

During MARAMP 2007, no COTS were observed at the 3 REA sites surveyed at Agrihan, but 4 of the 6 towed-diver surveys had recordings of COTS, with an overall mean density of 0.017 organisms 100 m^{-2} (SE 0.005). Among all towed-diver surveys around Agrihan, the survey completed in the northeast region had the highest mean density with 0.038 organisms 100 m^{-2} (Fig. 14.7.1c, bottom panel); segment densities from this survey ranged from 0 to 0.14 organisms 100 m^{-2}. The 2 surveys conducted along the western coast had mean COTS densities of 0.031 and 0.026 organisms 100 m^{-2}; segment densities from both these surveys ranged from 0 to 0.143 organisms 100 m^{-2}.

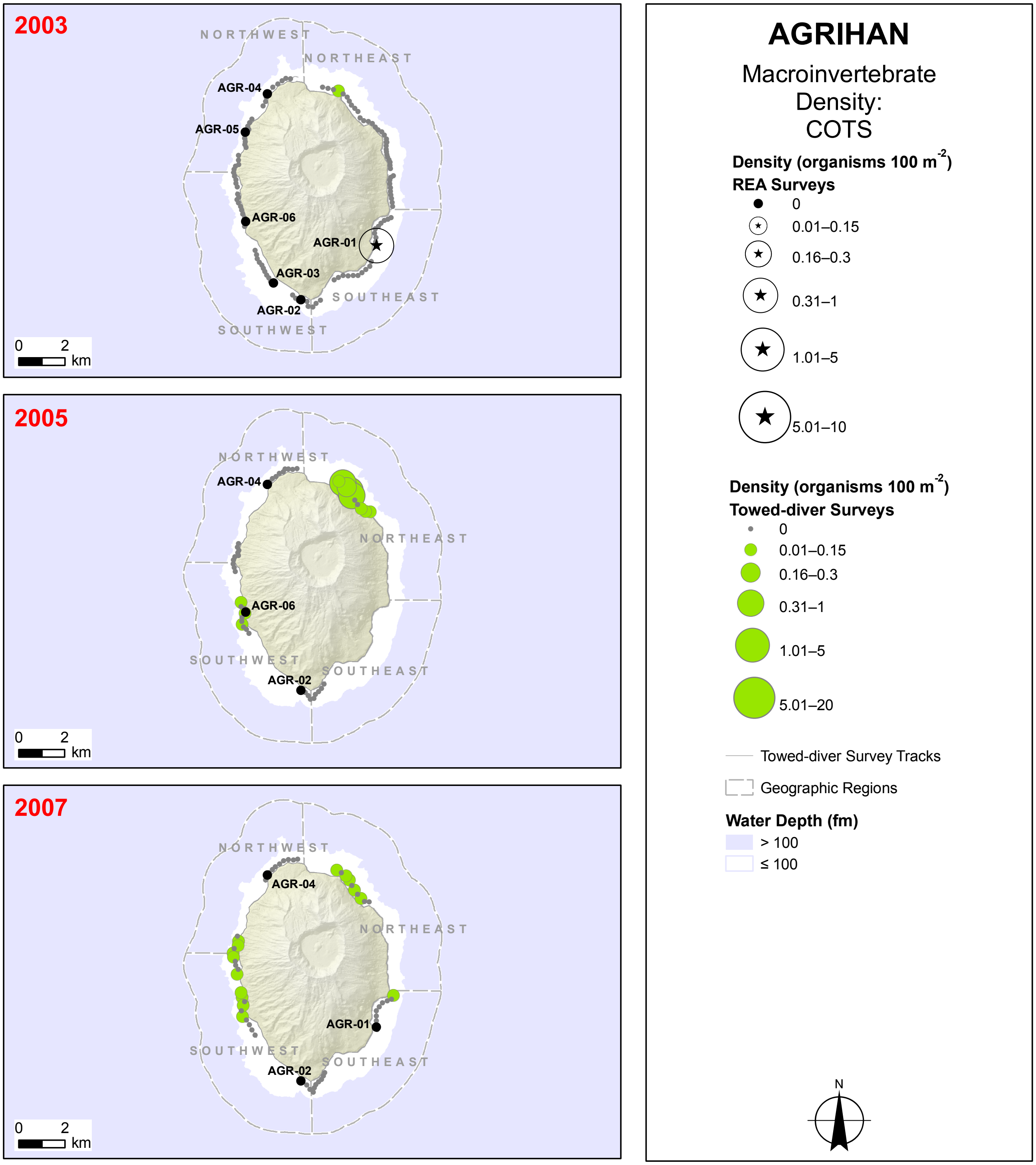


Figure 14.7.1c. Densities (organisms 100 m^{-2}) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007.

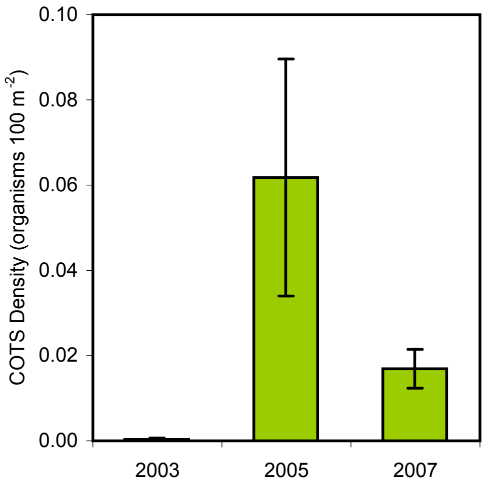


Figure 14.7.1d. Temporal comparison of COTS mean densities (organisms 100 m^{-2}) from towed-diver surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested that COTS densities around Agrihan were higher in 2005 than in 2003 and 2007 (Fig. 14.7.1d). Given that these corallivorous seastars can decimate a reef, understanding whether their observed densities signify an outbreak is important. By means of a manta-tow technique—which uses snorkel divers as observers in a manner similar to the procedure established for using scuba divers to conduct MARAMP towed-diver surveys—Moran and De'ath (1992) defined a potential outbreak as a reef area where the density of *A. planci* was > 1500 organisms km^{-2} (0.15 organisms 100 m^{-2}), and the level of dead coral present was at least 40%. Using this definition only in terms of density and considering each towed-diver survey as an individual reef area, only one localized area was found with relatively high densities that suggest it was undergoing an outbreak. This area was in the northeastern region where densities from towed-diver surveys during MARAMP 2005 were estimated at 0.29 organisms 100 m^{-2}.

Sea Cucumbers

During MARAMP 2003, sea cucumbers were observed at only 1 of the 6 REA sites surveyed and in 8 of the 12 towed-diver surveys conducted around Agrihan (Fig. 14.7.1e, top panel). The density of sea cucumbers at AGR-01 was 2 organisms 100 m^{-2}; these sea cucumbers were from the genus *Actinopyga*. The overall mean density of sea cucumbers from towed-diver surveys was 0.004 organisms 100 m^{-2} (SE 0.001). Among all towed-diver surveys around Agrihan, the survey completed in the southeast region had the highest mean density with 0.024 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.064 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers from a towed-diver survey was 0.01 organisms 100 m^{-2}, recorded along the southwestern shore; segment densities ranged from 0 to 0.101 organisms 100 m^{-2}.

During MARAMP 2005, no sea cucumbers were observed at the REA sites surveyed around Agrihan, but 2 of the 5 towed-diver surveys had recordings of sea cucumbers (Fig. 14.7.1e, middle panel), with an overall mean density of 0.003 organisms 100 m^{-2} (SE 0.002). The 2 towed-diver surveys with observations of sea cucumber were completed along the western shoreline with mean densities of 0.011 and 0.005 organisms 100 m^{-2}; segment densities from these surveys ranged from 0 to 0.058 organisms 100 m^{-2}.

During MARAMP 2007, no sea cucumbers were observed at the REA sites surveyed around Agrihan, but 3 of the 6 towed-diver surveys had recordings of sea cucumbers (Fig. 14.7.1e, bottom panel), with an overall mean density of 0.006 organisms 100 m^{-2} (SE 0.003). Among all towed-diver surveys around Agrihan, the survey completed along the western shore had the highest mean density of sea cucumbers with 0.014 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.143 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers was 0.01 organisms 100 m^{-2}, recorded along the southern shore; segment densities ranged from 0 to 0.06 organisms 100 m^{-2}.

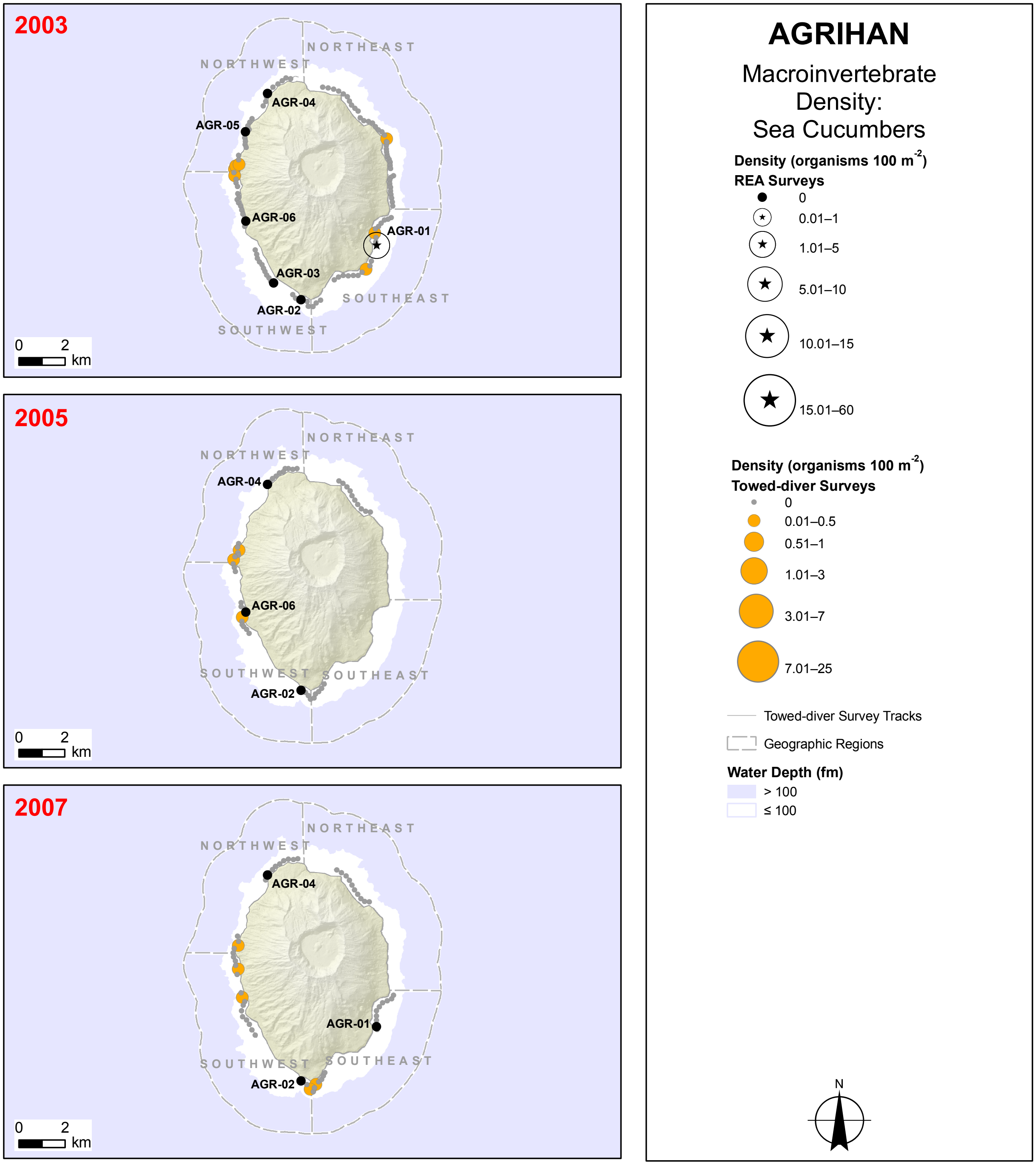


Figure 14.7.1e. Densities (organisms 100 m^{-2}) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007.

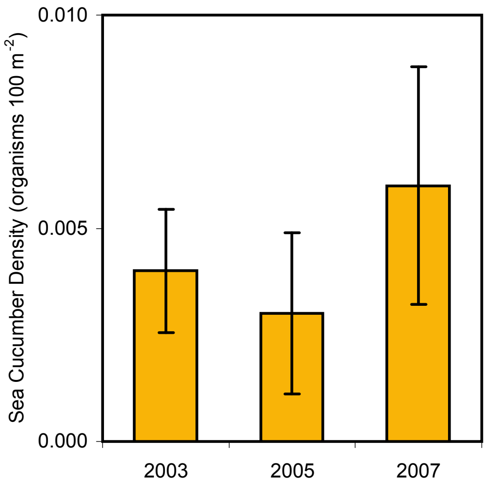


Figure 14.7.1f. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested extremely low daytime abundance of sea cucumbers around Agrihan during MARAMP 2003, 2005, and 2007, relative to the rest of the Mariana Archipelago. The overall observed mean density of sea cucumbers was relatively consistent between MARAMP survey years (Fig. 14.7.1f). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea cucumbers (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Sea Urchins

During MARAMP 2003, sea urchins were observed at all 6 REA sites surveyed and in 10 of the 12 towed-diver surveys conducted around Agrihan (Fig. 14.7.1g, top panel). The sample mean density from REA surveys was 29.33 organisms 100 m^{-2} (SE 15.76), and the overall mean density from towed-diver surveys was 2.69 organisms 100 m^{-2} (SE 0.52). Survey results suggest that sea urchins were most abundant at AGR-05 in the northwest region with a mean density of 90 organisms 100 m^{-2}. AGR-01 in the southeast region had the second-highest mean density with 66 organisms 100 m^{-2}. Rock-boring urchin species from the genus *Echinostrephus* were the dominant macroinvertebrates at all sites, accounting for 92% of sea urchins recorded at AGR-05 and AGR-01. Other genera observed were *Echinothrix, Echinometra,* and *Diadema*. The highest species diversity was found at AGR-05 with representatives from all 4 genera.

Among all towed-divers surveys conducted around Agrihan in 2003, the surveys completed along the western coast had the greatest mean densities with 7.38 and 5.1 organisms 100 m^{-2}; segment densities froms these surveys ranged from 0 to 38.73 organisms 100 m^{-2}. The third-greatest mean density from a towed-diver was 3.09 organisms 100 m^{-2}; recorded in the southeast region; segment densities from this survey ranged from 0 to 11.16 organisms 100 m^{-2}.

During MARAMP 2005, sea urchins were observed at 1 of the 3 REA sites surveyed and in all 5 towed-diver surveys conducted around Agrihan (Fig. 14.7.1g, middle panel). AGR-06 had a density of 3 organisms 100 m^{-2}; all of these urchins belonged to the genus *Echinothrix.* The overall mean density from towed-diver surveys was 0.48 organisms 100 m^{-2} (SE 0.22). Among all towed-diver surveys around Agrihan, the survey completed in the northeast region had the greatest mean density of 1.34 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 9.94 organisms 100 m^{-2}. The second-greatest mean density of sea urchins was 0.57 organisms 100 m^{-2}, recorded in the northwest region; segment densities ranged from 0 to 3.71 organisms 100 m^{-2}.

During MARAMP 2007, sea urchins were observed at 2 of the 3 REA sites surveyed and in all 6 towed-diver surveys conducted around Agrihan (Fig. 14.7.1g, bottom panel). The sample mean density from REA surveys was 11.89 organisms 100 m^{-2} (SE 8.22), and the overall mean density from towed-diver surveys was 0.40 organisms 100 m^{-2} (SE 0.13). Survey results indicate that sea urchins were most abundant at AGR-04 in the northwest region with a mean density of 27.67 organisms 100 m^{-2}. Species of the rock-boring genus *Echinostephus* accounted for all urchins recorded during REA surveys. Among all towed-diver surveys around Agihan, the survey completed in the southeast region had the greatest mean density of 0.8 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 3.92 organisms 100 m^{-2}. The second-greatest mean density of sea urchins was 0.67 organisms 100 m^{-2}, recorded along the western shoreline; segment densities ranged from 0 to 3.46 organisms 100 m^{-2}.

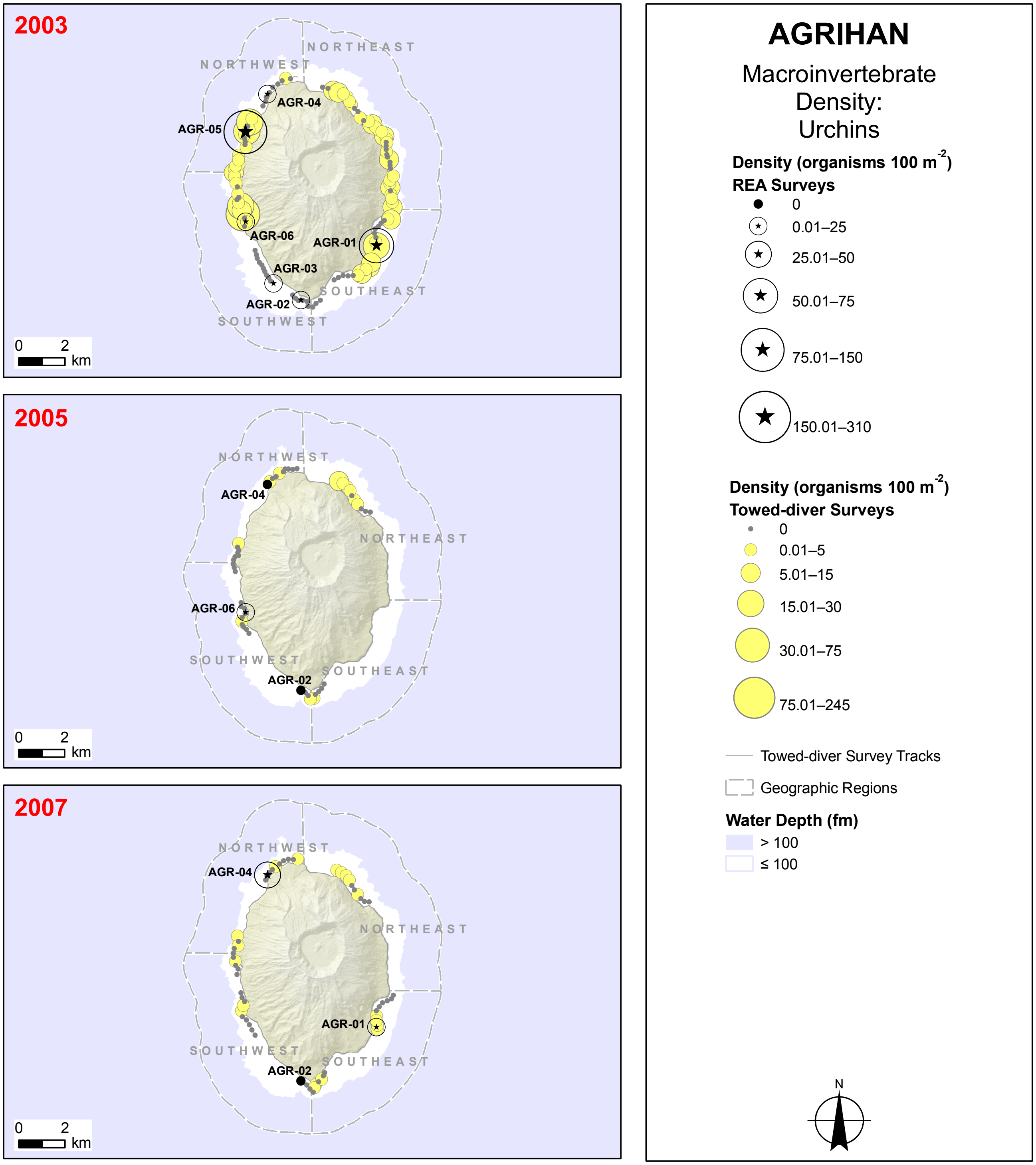


Figure 14.7.1g. Densities (organisms 100 m^{-2}) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007.

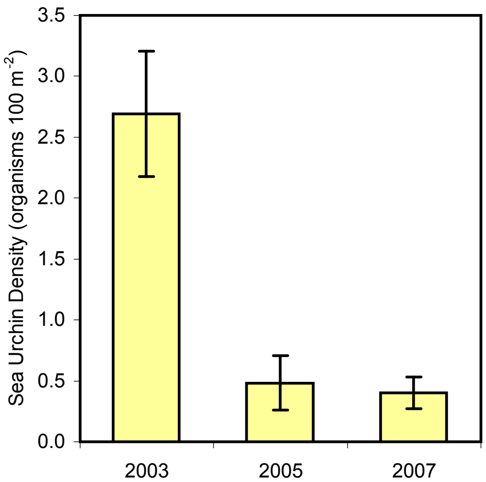


Figure 14.7.1h. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Agrihan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested low daytime abundance of sea urchins around Agrihan during MARAMP 2003, 2005, and 2007, compared to the rest of the Mariana Archipelago. The overall observed mean density of sea urchins around Agrihan was higher in 2003 than in 2005 and 2007 (Fig. 14.7.1h). This variation is not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

14.8 Reef Fishes

14.8.1 Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 12 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats around the island of Agrihan. The overall estimated mean biomass of large fishes, calculated as weight per unit area, was 0.84 kg 100 m^{-2} (SE 0.10). Biomass values for large fishes were highest in the northwest region, where sharks, snappers (Lutjanidae), and jacks (Carangidae) were common (Fig. 14.8.1a, top panel). Reef sharks (Carcharhinidae), nurse sharks (Ginglymostomatidae), and snappers together accounted for 70%, or 0.59 kg 100 m^{-2}, of islandwide mean large-fish biomass. Snappers composed the greatest proportion (33%) of islandwide mean large-fish biomass. The twinspot snapper (*Lutjanus bohar*) was the dominant snapper species, contributing 65% or 0.18 kg 100 m^{-2} of snapper biomass. Reef sharks alone accounted for 31% of overall mean biomass of large fishes, with the whitetip reef shark (*Triaenodon obesus*) and grey reef shark (*Carcharhinus amblyrhynchos*) contributing 0.12 kg 100 m^{-2} and 0.14 kg 100 m^{-2} of large-fish biomass.

During MARAMP 2005, 5 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats at Agrihan. The overall estimated mean biomass of large fishes was 0.87 kg 100 m^{-2} (SE 0.08). No clear spatial patterns were seen in the distribution of large-fish biomass at this island (Fig. 14.8.1a, middle panel). Reef sharks and nurse sharks together contributed 55% or 0.48 kg 100 m^{-2} of the overall large-fish biomass. The grey reef shark was the largest component (28%) of overall mean biomass of large fishes. Jacks comprised 19% of overall large-fish biomass. A large school of bigeye trevally (*Caranx sexfaciatus*) was observed in the northwest region.

During MARAMP 2007, 6 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats at Agrihan. The overall estimated mean biomass of large fishes was 1.22 kg 100 m^{-2} (SE 0.85). Biomass values for large fishes, as was seen in 2003, were highest in the northwest region, where sharks and jacks were common (Fig. 14.8.1a, bottom panel). Jacks, reef sharks, and nurse sharks together contributed 88% of overall mean large-fish biomass. Jacks composed the greatest proportion (61%) or 0.74 kg 100 m^{-2} of overall large-fish biomass. As in 2005, a large school of bigeye trevally was observed in the northwest region; consequently, this species accounted for a higher proportion of estimated large-fish biomass than other jacks. Sharks also were frequently seen in 2007 and contributed 27% of overall mean large-fish biomass. The tawny nurse shark (*Nebrius ferrugineus*) and grey reef shark had the highest biomass levels among shark species, contributing 0.12 kg 100 m^{-2} and 0.19 kg 100 m^{-2} of overall mean biomass of large fishes.

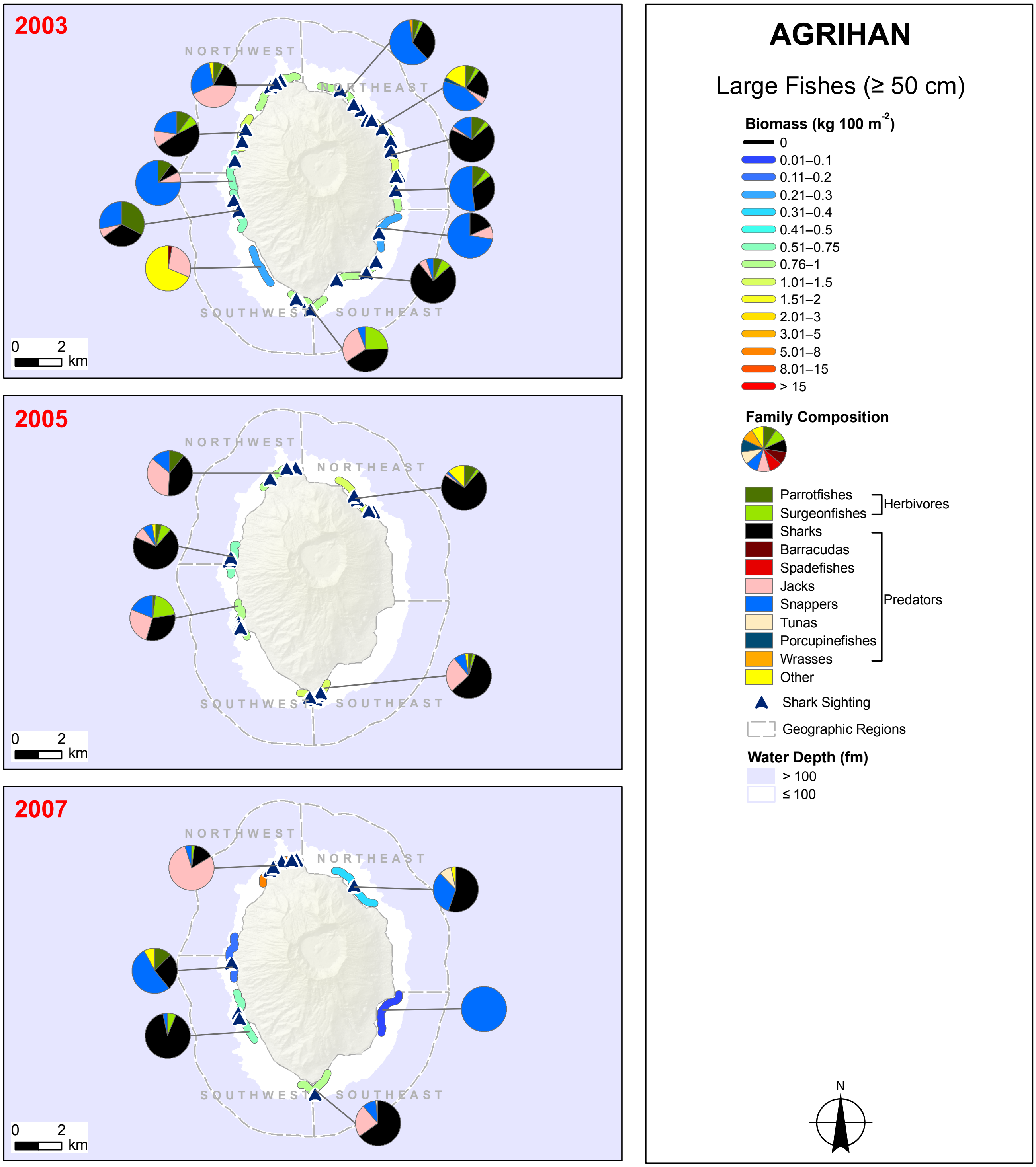
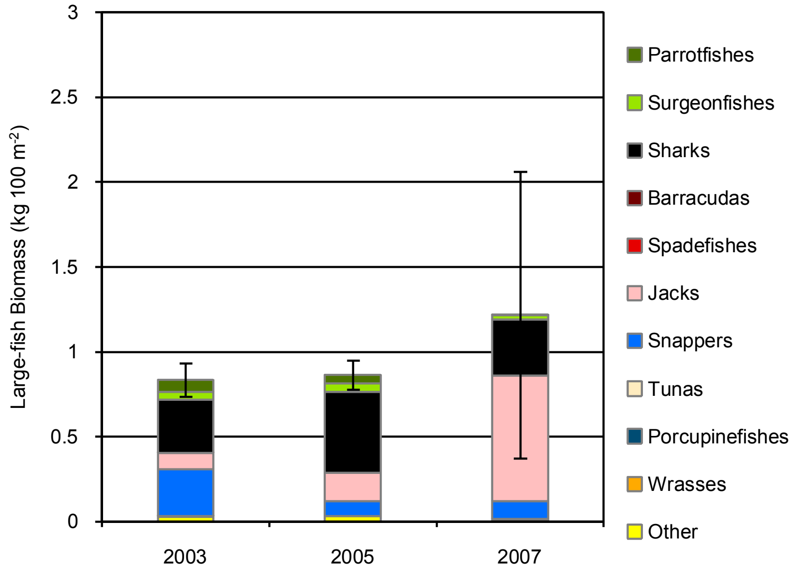


Figure 14.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

Compared to values recorded at other islands in the Mariana Archipelago, the overall large-fish biomass estimated at Agrihan was about average for observations at unpopulated islands in the Mariana Archipelago (Fig. 14.8.1b). Reef sharks and nurse sharks were common during the 3 MARAMP survey periods. Among shark species, the whitetip reef shark contributed the highest biomass values in 2003 and 2005, while the tawny nurse shark accounted for the highest biomass value in 2007. Snappers and jacks also were common during the 3 survey periods, and the twinspot snapper and bigeye trevally were the most abundant snapper and jack species. Notable observations included a single sighting of the humphead wrasse (*Cheilinus undulatus*) in 2003 and sightings of the dogtooth tuna (*Gymnosarda unicolor*) in 2007.

Figure 14.8.1b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver fish surveys of forereef habitats conducted around Agrihan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.



Total Fish Biomass

Total fish biomass for the 6 REA sites surveyed in forereef habitats at Agrihan during MARAMP 2003 was moderate, compared to other sites in the Mariana Archipelago, with an overall sample mean of 5.85 kg 100 m^{-2} (SE 1.34). The highest biomass was observed at AGR-05 in the northwest region (Fig. 14.8.1c, top panel), where a large school of dark-banded fusilier (*Pterocaesio tile*) was recorded. Surgeonfishes (Acanthuridae) accounted for the greatest proportion (20%) or 1.20 kg 100 m^{-2} of total fish biomass at Agrihan. The whitecheek surgeonfish (*Acanthurus nigricans*) was the largest contributor to surgeonfish biomass, accounting for 24% of surgeonfish biomass. Parrotfishes (Scaridae) accounted for the second-greatest proportion (11%) of total fish biomass. Two grey reef sharks were observed in 2003, both at AGR-03 in the southwest region.

Based on REA surveys conducted during MARAMP 2003, species richness at Agrihan ranged from 4 to 48 species 100 m^{-2}. The lowest diversity was seen at AGR-03 in the southwest region, while the highest diversity was found at AGR-05 in the northwest region (Fig. 14.8.1c, top panel). Among fish families observed at Agrihan, wrasses (Labridae) and surgeonfishes were the most represented with 29 and 15 species recorded. The ornate wrasse (*Halichoeres ornatissimus*) was the most abundant wrasse species, and the orangespine unicornfish (*Naso lituratus*) was the most abundant surgeonfish species. Damselfishes (Pomacentridae) dominated counts with the Vanderbilt's chromis (*Chromis vanderbilti*) and midget chromis (*C. acares*) as the 2 most often seen species.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Agrihan during MARAMP 2005 was moderately high, compared to other sites in the Mariana Archipelago, with an overall sample mean of 14.53 kg 100 m^{-2} (SE 3.67). The highest biomass of 21.87 kg 100 m^{-2} was observed at AGR-04 in the northwest region (Fig. 14.8.1c, middle panel). Reef sharks and surgeonfishes contributed the greatest proportions to total fish biomass at Agrihan. Reef sharks alone composed 19% of overall total fish biomass; 5 whitetip reef sharks were recorded. As in 2003, the whitecheek surgeonfish was the largest contributor (18%) to surgeonfish biomass. Groupers (Serranidae) also were common, with the peacock hind (*Cephalopholis argus*) and darkfin hind (*C. urodeta*) accounting for 78% of grouper biomass.

Based on REA surveys conducted during MARAMP 2005, species richness ranged from 31 to 46 fish species 100 m^{-2}. The highest diversity was found at AGR-04 in the northwest region (Fig. 14.8.1c, middle panel). Wrasses and surgeonfishes again were the most diverse families with 20 and 17 species recorded. The ornate wrasse was the most abundant wrasse species with an overall mean density of 17.60 individuals 100 m^{-2}. The striated surgeonfish (*Ctenochaetus striatus*) was the most abundant surgeonfish, but a number of other species were nearly as abundant: orangespine unicornfish, whitebar surgeonfish (*Acanthurus leucopareius*), brown surgeonfish (*A. nigrofuscus*), and whitecheek surgeonfish. The midget chromis was the most abundant of all species recorded at Agrihan, with an overall mean density of 106.70 individuals 100 m^{-2}.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Agrihan during MARAMP 2007 was fairly high, compared to other sites in the Mariana Archipelago, with an overall sample mean of was 11.32 kg 100 m^{-2} (SE 7.63). The highest biomass of 26.58 kg 100 m^{-2} was observed in the northwest region at AGR-04, where numerous sleek unicornfish

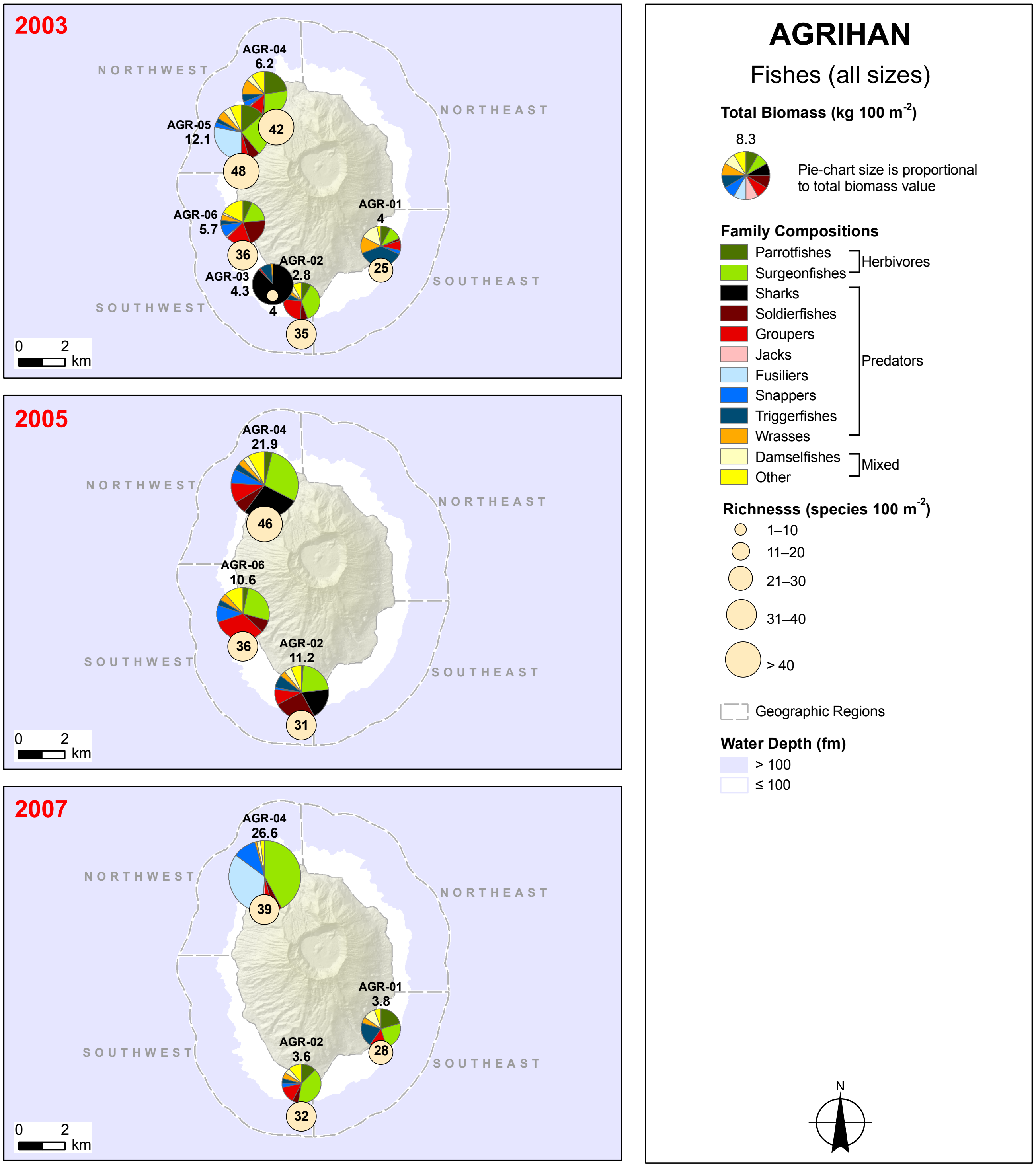


Figure 14.8.1c. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats at Agrihan during MARAMP 2003, 2005, and 2007.

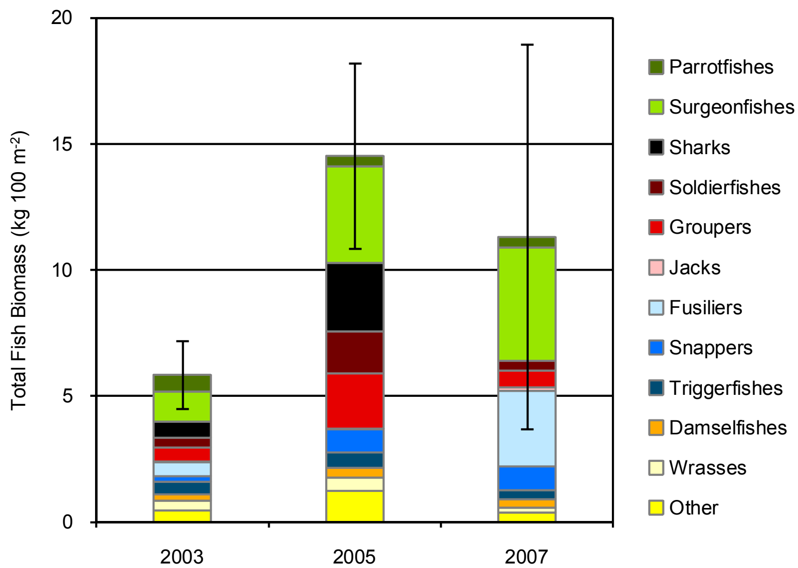
(*Naso hexacanthus*) and schools of dark-banded fusilier and yellow and blueback fusilier (*Caesio teres*) were recorded (Fig. 148.1c, bottom panel). Surgeonfishes accounted for the greatest proportion (40%) or 4.51 kg 100 m^{-2} of total fish biomass at Agrihan. The sleek unicornfish was the most abundant surgeonfish species, accounting for 46% of surgeonfish biomass. The whitecheek surgeonfish also was commonly recorded, contributing 19% of surgeonfish biomass. No sharks were observed during this survey period.

Based on REA surveys conducted during MARAMP 2007, species richness ranged from 28 to 39 species 100m^{-2}. The highest diversity was found at AGR-04 in northwest region (Fig. 148.1c, bottom panel). Wrasses, damselfishes, and surgeonfishes were the most represented families at Agrihan with 18, 13, and 13 species recorded. The ornate wrasse was the most abundant wrasse species, and the whitebar surgeonfish was the most abundant surgeonfish species. Damselfishes, as in 2003, dominated counts, and the midget chromis was the most abundant of all species with an overall mean density of 134.10 individuals 100 m^{-2}.

During each of the 3 MARAMP survey years, the highest mean total fish biomass from REA surveys conducted in forereef habitats at Agrihan was found in the northwest region. No clear temporal trend was observed, although the overall estimated mean for total fish biomass was highest in 2005, as a result of the observation of 5 whitetip reef sharks at AGR-04 (Fig. 14.8.1d). Surgeonfishes also were abundant, with the whitecheek surgeonfish, orangespine unicornfish, striated surgeonfish, and sleek unicornfish collectively contributing 52%–77% of total surgeonfish biomass over the 3 survey periods.

Site-specific estimates of species richness ranged from 4 to 48 species 100 m^{-2} over the 3 MARAMP survey years, with the highest species richness consistently observed in the northwest region. Wrasses and surgeonfishes were the 2 most diverse families with 22 and 15 species recorded. Damselfishes dominated counts, with the midget chromis and Vanderbilt's chromis as the most abundant damselfish species.

Figure 14.8.1d. Temporal comparison of mean total fish biomass (all species and size classes in kg 100 m^{-2}) values from REA fish surveys of forereef habitats conducted at Agrihan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.



14.9 Marine Debris

14.9.1 Marine Debris Surveys

During MARAMP 2003, no sightings of marine debris were recorded in the 12 towed-diver surveys conducted on forereef habitats around the island of Agrihan. During MARAMP 2005, 2 sightings of derelict fishing gear were documented in the 5 towed-diver surveys conducted on forereef habitats at Agrihan, (Fig. 14.9.1a). Two net fragments were observed near the border between the southeast and southwest regions. During MARAMP 2007, 2 sightings of derelict fishing gear were recorded in the 6 towed-diver surveys conducted on forereef habitats at this island. Net fragments were observed at 1 location in the southeast region, and 1 old fishing line was noted in the northwest region. No munitions, wrecks, or other man-made objects were identified during the 3 MARAMP survey years.

Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys in 2003, 2005, and 2007, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by the towed-divers in their observer comments.

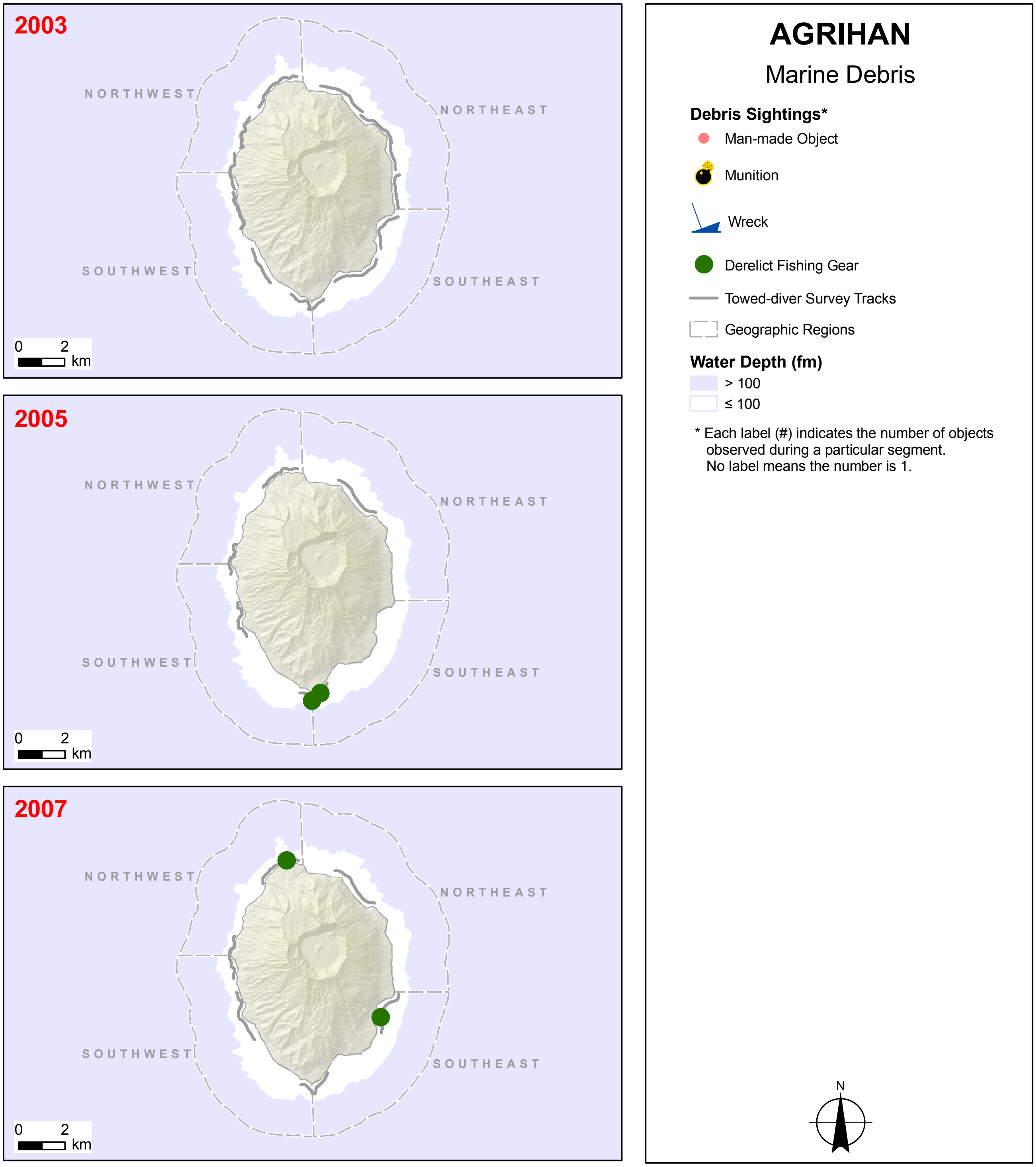


Figure 14.9.1a. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Agrihan during MARAMP 2005 and 2007. No debris sightings were recorded in 2003. Symbols indicate the presence of specific debris types.

14.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Agrihan are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. In addition to this island-level analysis, evaluations across the entire Mariana Archipelago are presented in Chapter 3: "Archipelagic Comparisons," including archipelago-wide reef condition indices with ranks for Agrihan and the other 13 islands covered in this report.

Agrihan is the tallest island in the Mariana Archipelago with a maximum elevation of 965 m at the summit crater rim. This island's summit crater is surrounded by steep slopes that continue underwater, dominating the submarine topography. The only historic volcanic eruption recorded at Agrihan occurred in 1917. The lava flow from this eruption breached the summit cone and can be seen both onshore (Figure 14.1.2a, in Section 14.1.2: "Geography"), where it extends the coastline north-northwest of this island, and in adjacent waters, where it created a small, shallow ridge (Figure 14.3.1c, in Section 14.3.1: "Acoustic Mapping"). From observations made during towed-diver surveys, this ridge appeared to support live-hard-coral cover at a slightly higher level (10%–40%) than did the surrounding area during the 3 MARAMP survey years (Figs. 14.10a and b). The habitat in this location was described by towed divers as continuous reef with ridges, some with very high vertical relief and depth changes, and occasional boulder fields.

Figure 14.10a. A northern reef at Agrihan. *NOAA photo by Robert Schroeder*

In the nearshore waters around Agrihan, steep volcanic flanks are interrupted by a shallow shelf at depths of 30–40 m (see Figures 14.3.1b and c in Section 14.3.1: "Acoustic Mapping"). Along southwest Agrihan, the surface of this hard shelf is covered by sand (see Figures 14.3.1g and 14.3.3a in Section 14.3: "Benthic Habitat Mapping and Characterization") and supports little or no cover of live corals or macroalgae (Fig. 14.10b). At the southern tip of this island, in an area where this shelf narrows, high levels of coral cover, relative to other survey areas around Agrihan, were observed during towed-diver surveys in each of the 3 MARAMP survey periods. REA benthic surveys conducted at AGR-02 in the same location had the highest values of coral-colony density and coral cover recorded at REA sites at this island (see Figure 14.5.1b in Section 14.5.1: "Coral Surveys").

On the more exposed east side of Agrihan, the continuing shelf supported low levels of live coral cover, except for one location in the northeast region, where the coastline protrudes slightly and a towed-diver survey ran closer to the shelf edge. Here, coral cover of up to 40% was recorded (Fig. 14.10b, top panel). Elsewhere in the northeast region, live coral cover was low, and high densities of COTS observed in 2005 likely resulted in relatively high levels of stressed-coral cover in this region (see Figure 14.5.1a in Section 14.5.1: "Coral Surveys"). High values of macroalgal cover were recorded on

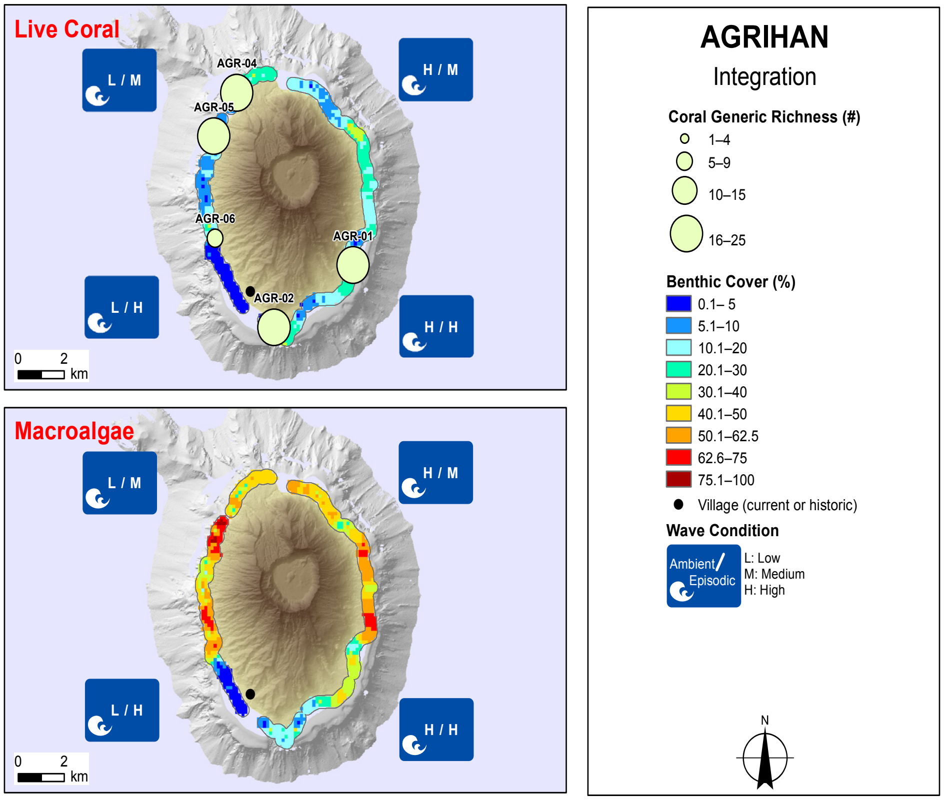


Figure 14.10b. Cover (%) observations of live hard corals and macroalgae from towed-diver benthic surveys and coral generic-richness values from REA benthic surveys conducted on forereef habitats at Agrihan during MARAMP 2003, 2005, and 2007. Values of coral cover and macroalgal cover represent interpolated values from the 3 survey years, and values of coral generic richness represent averages of data from the 3 survey years. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region.

the shelf in the northeast region, compared to other survey areas around southern Agrihan, during towed-diver surveys in each of the 3 survey years. The habitat in this region, as described by towed divers, consisted predominantly of boulders on sand interspersed with pavement.

In the northern section of the southwest region, towed-diver surveys were conducted close to the shelf edge because it runs close to shore. Towed divers found a hard pavement habitat with low sand cover (see Figure 14.3.3a in Section 14.3.3: “Habitat Characterization”), low cover of live corals (predominantly < 30%), and very high macroalgal cover (frequently 75%–100%; Fig. 14.10b, bottom panel), compared to other areas surveyed at Agrihan. Similarly, in the southern part of the northwest region, low cover of live corals and abundant macroalgae were observed, although the habitat type in this area was very different with high-relief, spur-and-groove formations, and boulders collected in channels.

Oceanographic conditions observed around Agrihan showed some spatial variability. Shallow-water CTD casts conducted around this island in 2003 and 2005 suggested that water temperatures were cooler and salinity values were higher in the northern regions than in the well-mixed waters of the southern regions (see Figures 14.4.1a and c in Section 14.4.1: “Hydrographic Data”). This pattern was not seen in 2007, when results from CTD casts in nearshore waters around Agrihan suggested less variation than in previous survey years, apart from one cast location in the southeast region where localized upwelling was observed (Fig. 14.4.1e). Variation between MARAMP survey years may result from differences in season (MARAMP 2007 occurred in May and MARAMP 2003 and 2005 occurred in August and September).

The fish communities observed at Agrihan appeared to have levels of large-fish biomass comparable with estimates for other northern islands in the Mariana Archipelago (see Figure 14.8.1a in Section 14.8.1: “Reef Fish Surveys”; for more details, also see Chapter 3: “Archipelagic Comparisons”). The greatest proportion of overall large-fish biomass was contributed by reef sharks, which were seen regularly during each of the 3 MARAMP survey years. Surgeonfishes also were common, with the whitecheek surgeonfish (*Acanthurus nigricans*), orangespine unicornfish (*Naso lituratus*), striated surgeonfish (*Ctenochaetus striatus*), and sleek unicornfish (*Naso hexacanthus*) collectively constituting 52%–77% of surgeonfish biomass across the 3 survey periods (Fig. 14.10c). With the exception of the low species richness observed at the single REA site that was surveyed only in 2003, fish diversity was relatively high at Agrihan with 25–48 species per site (Fig. 14.8.1c). The superior condition of the fish community at Agrihan, compared to the communities observed at other islands in the Mariana Archipelago, may result from the relative isolation of this island, which is ~ 400 km from Saipan, the nearest densely populated island.

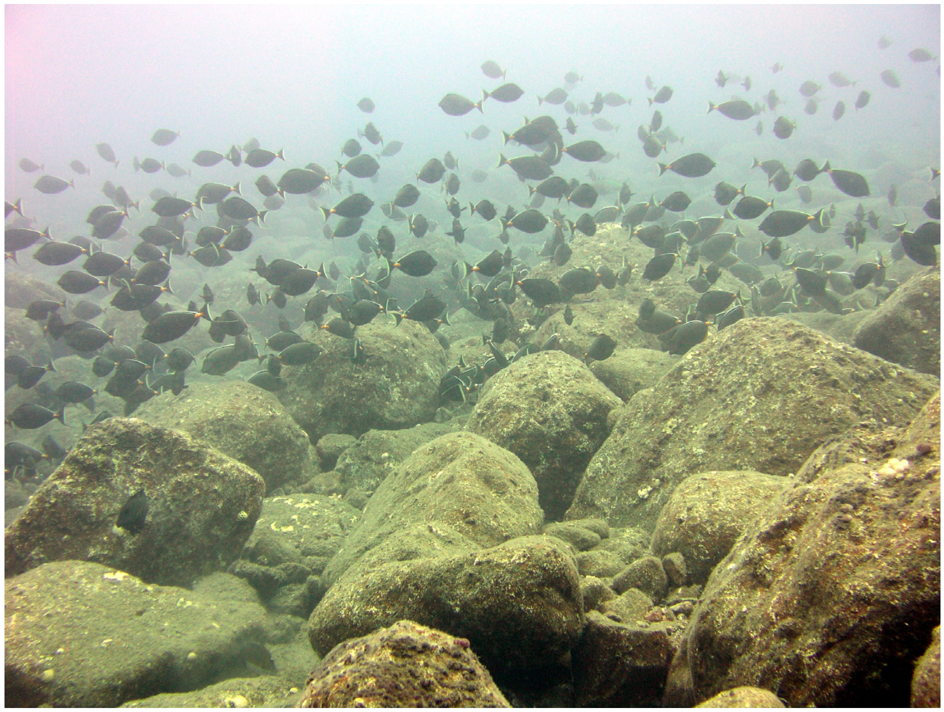


Figure 14.10c. A school of orangespine unicornfish (*Naso lituratus*) at a boulder habitat at Agrihan. *NOAA photo by Robert Schroeder*

14.11 Summary

MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats around Agrihan. Methodologies and their limitations are discussed in detail in Chapter 2: "Methods and Operational Background," and specific limitations of the data or analyses presented in this Agrihan chapter are included in the relevant discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter. The conditions of the fish and benthic communities and the overall ecosystem around Agrihan, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: "Archipelagic Comparisons."

This section presents an overview of the status of coral reef ecosystems around the island of Agrihan and some of the key natural processes influencing these ecosystems:

- Agrihan is 65 km north of Pagan and is one of the largest northern islands in the Mariana Archipelago with a land area of 44.05 km^2.

- Inhabitation of Agrihan has been sporadic over the last 100 years because of volcanic activity. One of the 4 original villages has been resettled, making Agrihan the only island north of Saipan that currently may have a permanent human population.

- As the tallest island in the Mariana Archipelago, with a summit elevation of 965 m, Agrihan is surrounded by steep slopes and sea cliffs.

- Agrihan's seascape is similarly characterized by steep volcanic flanks, which are incised by channels. North-northwest of Agrihan, a lava flow created a submarine ridge and extended the coastline in this area. A shallow shelf is present around this island at depths of 30–40 m.

- Habitats of medium to high complexity were observed in the northwest region and northern part of the southwest region, with low sand cover and primarily low cover of live hard corals compared to levels recorded at other islands in the Mariana Archipelago. Coral cover was higher in the survey area adjacent to the onshore lava flow than in the rest of the northwest region.

- The northeast region of Agrihan had habitats of medium-low to high complexity, including pavement, boulders on sand, and rocky ridges. In the southern part of this region, live coral cover of 10%–50% was recorded adjacent to a flat area observed on the island topography.

- In the southeast region, an area with habitat of low complexity was observed. Sand cover as high as 75%–100% and low cover (< 10%) of live hard corals was recorded during towed-diver surveys of the wide bays of this coastline. That habitat alternated with patches of medium-relief, spur-and groove habitat of higher complexity with lower sand cover (< 30%) and higher live coral cover (10%–62.5%).

- Southwest of Agrihan, a large area had habitat of low to medium-low complexity characterized by high sand cover (75%–100%) and very low coral cover (< 5%).

- Wave model output shows ambient trade wind swells impacting the northeast and southeast regions. Episodic wave energy from storm tracks impacts the southwest and southeast regions and to a lesser extent the northeast and northwest regions.

- Some spatial heterogeneity was seen in 2003 and 2005, with northern waters cooler and more saline than the well-mixed waters in the southern regions. In 2007, water masses around Agrijan were homogeneous, although a large range in water temperatures (3.2˚C) was recorded via nearshore CTD casts. This broad range in temperatures was likely a result of localized upwelling of subsurface waters in the southeast region and to a lesser extent the northwest region.

- Subsurface temperature values from an STR deployed at a depth of 2 m in the southwest region exceeded the coral bleaching threshold in September 2006; however, the duration of this event was < 1 d.

- Observed cover of live hard corals, based on towed-diver surveys, was fairly consistent between the 3 MARAMP survey years, with overall means of 14%–16%. The overall sample mean for live coral cover estimated from REA surveys conducted at 3 sites in 2007 was 30.7%.

- The same 3 REA sites also were surveyed for coral disease in 2007, and overall mean prevalence of disease was 0.01%. Three disease states were recorded: fungal infection, skeletal growth anomalies, and bleaching. Only one case of COTS predation was detected.

- Observations of COTS from towed-diver surveys were virtually nonexistent in 2003. In 2005, observed densities of COTS in the northeast and southwest regions were much higher than densities seen in 2003. A localized area in the northeast region had densities suggesting a possible COTS outbreak. By 2007, population densities had declined.

- During each of the 3 MARAMP survey years, overall observed mean density of sea cucumbers was extremely low and abundance of giant clams was low at Agrihan, compared to densities observed at other islands in the Mariana Archipelago.

- Between MARAMP 2005 and 2007, average cover of macroalgae from towed-diver surveys at Agrihan decreased considerably, by more than 60%. Consistently, in each of the 3 survey years, reefs in the northeast region had the highest macroalgal cover recorded during towed-diver surveys.

- Overall mean crustose-coralline-red-algal cover from towed-diver surveys was < 10% during each of the 3 MARAMP survey years, with little temporal variation. No cases of coralline-algal disease were registered at Agrihan.

- The overall mean large-fish biomass, estimated from towed-diver surveys, was moderate in each of the 3 MARAMP survey years, relative to results from other islands surveyed in the Mariana Archipelago.

- The highest mean biomass from REA surveys for fishes of all sizes was found in the northwest region during the 3 MARAMP survey years. No clear temporal trend was observed, although total mean biomass for Agrihan was highest in 2005 at 14.53 kg 100 m^{-2}, likely a result of the sighting of 5 reef sharks at AGR-04 in the northwest region.

- Mean species richness of reef fishes at Agrihan ranged from 4 to 48 species 100 m^{-2} over the 3 survey years, with the highest species richness consistently observed in the northwest region.

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